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PLANT-BREEDING

Garden-Craft Series

The Horticulturist's Rule-Book
Plant-Breeding

PLANT-BREEDING

BEING SIX LECTURES UPON THE AMELIORATION OF DOMESTIC PLANTS

BY

L. H. BAILEY

FOURTH EDITION

WITH A NEW CHAPTER ON CURRENT
PLANT-BREEDING PRACTICE

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PREFACE.

THERE is no subject associated with the care of plants respecting which there is so much misapprehension and imperfect knowledge, as that of the origination of new forms. Most of the scattered writing touching it treats the subject as if all our knowledge of the matter were and must be derived wholly from experiment. It therefore recites examples of how this and that new form has come to be, and has made little attempt to discover the fundamental causes of the genesis of the novelties. Horticulturists commonly look upon each novelty as an isolated fact, whilst we ought to regard each one as but an expression of some law of the variation of plants. It is the common notion, too, to consider any type of plant to be essentially a fixed entity, and to regard any marked departure from the type as a phenomenon rather more to be wondered at than to be explained. It is evident, however, that one cannot understand the production of new varieties until he has grasped some of the fundamental principles of the onward progression of the vegetable kingdom. Any attempt, therefore, to explain the origin of garden varieties, and the methods of producing them, must be at the same time a contribution to the literature of the philosophy of organic evolution.

I do not know of any explicit and sustained attempt to account for the evolution of all garden forms, and I have therefore brought together in this volume the subject-matter of various lectures which I have been in the habit of giving before my students. The first and third lectures were newly elaborated the present summer for two addresses before the class in biology which came together at the University of Pennsylvania, under the auspices of the American Society for the Extension of University Teaching. The second lecture was first presented before the Massachusetts State Board of Agriculture, in Boston, December 1, 1891. In April, 1892, it was republished, with a bibliography of the subject, by the Rural Publishing Co., under the title, "Cross-Breeding and Hybridizing." This publication is now out of print. I have made no attempt to collect lists or catalogues of varieties, but have endeavored to make very brief statements of some of the underlying principles of the amelioration of plants, with only sufficient examples to fix them in the mind.

I hope that teachers of horticulture and botany may find the book useful in their classes. When it is necessary to abridge the instruction or to present it to untrained students, only Lectures III. and V. may be used, for these contain the matters of greatest demonstrative importance.

L. H. BAILEY.

CORNELL UNIVERSITY,
ITHACA, N.Y., September 1, 1895.

PREFACE TO THIRD EDITION.

In the eight years since this book was sent to the printer, there have been great changes in our attitude toward most of the fundamental questions that are discussed in its pages. In fact, these years may be said to have marked a transition between two habits of thought in respect to the means of the evolution of plants, — from the points of view held by Darwin and the older writers to those arising from definite experimental studies in species and varieties. We have not given up the old nor wholly accepted the new, but it is certain that our outlook is shifting. So far as practical plant-breeding is involved, the changing attitude is concerned chiefly with discussions of the nature of varieties and the nature of hybridization.

The chief practical result of the discussion of the nature of varieties is a re-defining of what a variety is, whereby we have come to recognize the fact, more clearly than heretofore, that not all differences in plants are of equal importance or significance.

The practical result of the discussions of hybridization is the growing belief that the offspring of hybridization follow definite laws. This statement seems to be wholly at issue with the tenor of Lecture II.; but the apparent contradictions are largely such as follow from two sets of definitions of the ideas of "variety" and "hybrid." It must also be remembered that even if hybridization follows definite laws, the practical results are commonly so modified and obscured by interfering circumstances that safe predictions usually cannot be made. I had once thought of rewriting Lecture II., but on going over it again I found that the chief change that I should desire now to make would be a rephrasing in order to conform it to the method of current discussions. Moreover, we are not yet ready to make very positive discussions from the newer studies. The time cannot be far distant when the subject of plant-breeding will be rewritten from a new point of view. In the meantime, I hope that the new matter in

Lecture IV. may set the reader straight on some of the newer problems.

The first issue of this book was made late in 1895. The second edition was made early in 1902. In the meantime it had been twice reprinted. By an inadvertence, the second edition was not so marked on the title-page. In that edition the changes in the text were few. The only very important departure was the publication of a bibliography. This bibliography had appeared with my paper on "Cross-Breeding and Hybridizing," which was published in 1892 as one of the Rural Library Series. It was purposely confined to such literature as English-speaking horticulturists would be most likely to find. The edition was soon exhausted, and many requests for this bibliography decided me to extend and republish it. In the present edition I have added somewhat to this bibliography (to the close of 1902), and have made some changes in the text; but the leading change is the substituting of new matter for the old Lecture IV.

L. H. Bailey

Cornell University,
Ithaca, N.Y., September 1, 1903.

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LECTURE I.

THE FACT AND PHILOSOPHY OF VARIATION.

THERE is no one fact connected with horticulture which so greatly interests all persons as the existence of numerous varieties of plants which seem to satisfy every need of the gardener. Whence came all this multitude of forms? What are the methods employed in securing them? Are they simply isolated facts or phenomena of gardening, or have they some relation to the broader phases of the evolution of the forms of life? These are some of the questions which occur to every reflective mind when it contemplates an attractive garden, but they are questions which seem never to be answered. Whatever attempt the gardener may make at answering them is either befogged by an effort to define what a variety is, or else it consists in simply reciting how a few given varieties came to be known. But there must be some fundamental method of arriving at a conception of how the varieties of fruits and flowers and other cultivated plants have originated. If there is no such method, then the origination of these varieties must follow no law, and the discussion of the whole subject is fruitless. But we have every confidence in the consecutive uniformity of the operations of nature, and it were strange if some underlying principle of the unfolding or progression of plant life does not dominate the origin of the varied and innumerable varieties which, from time unknown, have responded to the touch of the cultivator. Let us first, therefore, make a broad survey of the subject in a philosophical spirit, and, later, discuss the more specific instances of the origination of varieties.

I. THE FACT OF INDIVIDUALITY.

There is universal difference in nature. No two living things are exact counterparts, for no two are born into exactly the same conditions and experiences. Every living object has individuality; that is, there is something about it which enables the acute observer to distinguish it from all other objects, even of the same class or species. Every plant in a row of lettuce is different from every other plant, and the gardener, when transplanting them, selects out, almost unconsciously, some plants which please him and others which do not. Every apple tree in an orchard of a thousand Baldwins is unlike every other one, perhaps in size or shape, or possibly in the vigor of growth or the kind of fruit it bears. Persons who buy apples for export know that fruit from certain regions stands the shipments better than the same variety from other regions; and if one were to go into the orchards where these apples are grown, he would find the owner still further refining the problem by talking about the merits of individual trees in his orchard. If one were to make the effort, he would find that it is possible to distinguish differences between every two spears of grass in a meadow, or every two heads of wheat in a grain-field.

All this is equivalent to saying that plants are infinitely variable. The ultimate causes of all this variation are beyond the purpose of the present discussion, but it must be evident, to the reflective mind, that these differences are the means of adapting the innumerable individuals to every little difference or advantage in the environment in which they live. And if the result of variation is better adaptation to the physical conditions of life, then the same forces must have been present in the circumstances which determined the birth of the individual. The variation in environment, therefore, must be the cause of much of the variation in plants, since differences in plants were positively injurious if it were possible for the conditions of environment to be the same.

If no two plants are anywhere alike, then it is not strange if now and then some departure, more marked than common, is named and becomes a garden variety. We have been taught to feel that plants are essentially stable and inelastic, and that any departure from the type is an exception and calls for immediate explanation. The fact is, however, that plants are essentially unstable and plastic, and that variation between the individuals must everywhere be expected. This erroneous notion of the stability of organisms comes of our habit of studying what we call species. We set for ourselves a type of plant or animal, and group about it all those individuals which are more like this type than they are like any other, and this group we name a species. Nowadays, the species is regarded as nothing more than a convenient and arbitrary expression for classifying our knowledge of the forms of life, but the older naturalists conceived that the species is the real entity or unit in nature, and we have not yet wholly outgrown the habit of mind which was born of that fallacy. Nature knows nothing about species; she is concerned with the individual, the ultimate unit. This individual she moulds and fits into the chinks of environment, and each individual tends to become the more unlike its birthmates the more the environments of the various individuals are unlike. I would impress upon you, therefore, as a fundamental conception to the discussion of the general subject before us, the importance of the individual plant, rather than the importance of the species; for thereby we put ourselves as nearly as possible in a sympathetic attitude with nature, and, resting upon the ultimate object of her concern, we are able to understand what may be conceived to be her motive in working out the problem of life. That I may still more forcibly emphasize this thought, let me recall to your minds the fact that the whole tendency of contemporary civilization, in sociology and religion, is to deal with the individual person and not with the mass. This is only an unconscious feeling after natural methods of solving the most complex of problems, for it is exactly the means to which every organic thing has been subjected from the beginning.

In looking for the ultimate unit or individuality or personality in nature, we must make a broad distinction between the animal and the plant. Every higher animal is itself a unit; it is one. It has a more or less definite span of life, and every part and organ contribute a certain indispensable part to the life and personality of the organism. No part is capable of propagating itself independently of the sex-organs of the animal, nor is it capable of developing sex-organs of its own. If any part is removed, the animal is maimed and perhaps it dies. The plant, on the contrary, has no definite or distinct autonomy. Most plants live an indefinite existence, dependent very closely upon the immediate conditions in which they grow. Every part or branch of the plant lives largely for itself, it is capable of propagating and multiplying itself when removed from the parent plant or the colony of branches of which it is a member, and it develops sex-organs and other individual features of its own. If any branch is removed, the tree or plant does not necessarily suffer; in fact, the remaining branches usually profit by the removal, a fact which shows that there is a competition, or struggle for existence, between the different branches or elements of the plant. The whole theory and practice of pruning rest upon the fact of the individual unlikenesses of the branches of plants; and these unlikenesses are of the same kind and often of the same degree as those which exist between different plants which are grown from seeds. That is, the branches of a Crawford peach tree, for example, differ amongst themselves in size, shape, vigor, productiveness, and season of maturity, the same as any two or more separate Crawford trees, or any number of trees of other varieties, differ the one from the others. If any one of these branches or buds is removed and is grown into an independent tree, a person could not tell — if he were ignorant of its history — if this tree were derived from a branch or a seed. This proves that there is no essential unlikeness between branches and independent plants, except the mere accident that one grows upon another branch or plant whilst the other grows in the ground. But the branch may be severed and grown in the ground, and the seedling may be pulled up and grafted on the tree, and no one can distinguish the different origins of the two. And then, as a matter of fact, a very large proportion of our cultivated plants are not distinct plants at all, in the sense of being different creations from seeds, but are simply the results of the division of branches of one original plant or branch. All the fruit trees of any one variety are obtained from the dividing up and multiplication of the branches of the first or original tree.

You are now curious to know how this original tree came to be, and this I hope to tell you before I am done; but for the present, let me impress it upon you that it is equally possible for it to have come from a seed, or to have sprung from a branch which some person had noticed to be very different from the associated branches in the tree-top. In other words, the ultimate unit or individual of variation is the bud and the bit of wood or tissue to which it is attached; for every bud, like every seed, produces an offspring which can be distinguished from every other offspring whatsoever.

II. The Causes of Individual Differences.

We have now gotten back to the starting-point, to that unit with which nature begins to make her initial differences or individualities; that is, to the point where variations arise. This unit is the bud and the seed,—one sexless, or the offspring of one parent; the other sexual, or the offspring of two parents. Now, inasmuch as the horticultural variety is only a well-marked variation which the gardener has chanced to notice and to propagate, it follows that the only logical method of determining how garden varieties originate is to discover the means by which plants vary or differ one from another.

There is probably no one fact of organic nature concerning the origin of which modern philosophers are so much divided as the genesis or reasons for the beginnings of variations or differences. It seems to be an inscrutable problem, and it would be useless, therefore, for us to attempt to discover these ultimate forces in the present hour. Still, we must give them sufficient thought to enable us to satisfy our minds as to how far these variations may be produced by man; and, in doing this, we must discover at least the underlying philosophy of plant variation. It is the nature of organisms to be unlike their parents and their birthmates. Why?

a. *Fortuitous Variation.*

It will probably never be possible to refer every variation to a distinct cause, for it is probable that some of them have no antecedent. If we conceive of the forms of life as having been created with characters exactly uniform from generation to generation, then we should be led to look for a distinct occasion or cause for every departure from the type; but we know, as I have already pointed out, that heredity by its very nature is not so exact as to carry over every attribute, and no other, of the parent to the offspring. Elasticity, plasticity, is a part of the essential constitution of all organic beings. There is probably no inherent tendency in organisms towards any ultimate or predetermined completion of form, as the older naturalists supposed, but simply a laxity or indefiniteness of constitution which is expressed in numberless minor differences in individuals.

That is, some variation is simply fortuitous, an inevitable result of the inherent plasticity of organisms, and it has no immediate inciting cause. If we were to assume that every minor difference is the result of some immediate cause, then we should expect every individual plant or animal to fill some niche, to satisfy some need, to produce the definite effect for which the cause stands. But it is apparent to one who contemplates the operations of nature that very many — certainly more than half — of the organisms which are born are not useful to the perpetuity of the species and very soon perish. From these fortuitous variations nature selects, to be sure, many individuals to be the parents of other generations because they chance to be fitted to live, but this does not affect the methods or reasons of their origin. It is possible that, whilst many of these mere individual differences have no direct and immediate cause, they may still be the result of a devious line of antecedent causes long since so much diffused and modified that they will remain forever unrecognizable ; but even if so, the fact still remains that these present differences or variations may be purposeless, and it is quite as well to say that they exist because it is a part of the organic constitution of living things that unlike produces unlike.

b. *Sex as a Factor in the Variation of Plants.*

All plants have the faculty, either potential or expressed, of propagating themselves by means of buds, or asexual parts. This is obviously the cheapest and most direct possible method of propagation for many-membered plants, since it requires no special reproductive organization and energy, and, as only one parent is concerned in it, there is none of the risk of failure which resides in any mode of propagation in which two parents must find each other and form a union. There must be some reason, therefore, for the existence of such a costly mechanism as sex aside from its use as a mere means of propagation. It may be said that it exists because it is a means of more rapid multiplication than bud-propagation, but such is not necessarily the fact. There are many plants which produce buds as freely as they produce seeds; and then, if mere multiplication were the only destiny of the plant, bud-production would no doubt have greatly increased to have met the demand for new generations. The chief reason for the existence of sex in the vegetable world seems to be the need for a constant rejuvenation and modification of the offspring by uniting the features of two individuals into one. There thus arises from every sexual union a number of new or different forms from which nature may select the best, — that is, those best fitted to live in the conditions in which they chance to be placed. But whilst sex is undoubtedly one of the most potent sources of present unlikenesses, it is not necessarily an original cause of individual differences, since the two parties to any sexual contract must be unlike before they can produce unlike. When once the initial unlikenesses were established, every new sexual union would produce new combinations, so that now, when every new form, from whatever source it appears, comes into existence, there are other intimately related forms with which it may cross. This state of things has existed to a greater or less degree from the moment sex first appeared, so that the organic world is now endlessly varied as the result of a most complex ancestry.

The variety which sexual union has introduced into the world performs such an important part in the evolution of the forms of plants, and the problems which it presents are so complex, that I shall leave the whole subject for an independent discussion (Lecture II.).

c. *Physical Environment and Variation.*

Every phase and condition of physical circumstances, which are not absolutely prohibitive of plant life, have plants which thrive in them.

Every soil and climate, every degree of humidity, hills, swamps, and ponds, — every place is filled with plants. Even the trunks and branches of trees support other plants, as epiphytes and parasites. That is, plants have adapted themselves to every physical environment; or, to turn the proposition around, every physical environment produces adaptive changes in plants. There are those, like Weismann and his adherents, who contend, from purely speculative reasons, that these changes do not become hereditary or permanent until they have influenced a certain physiological substance which is assumed to reside in the reproductive regions of the organism, and that all those changes which have not yet reached this germ-plasm are, therefore, lost, or die with the organism. It is not necessary to combat this philosophy, for we know, as a matter of common horticultural experience, that every change or variation in any organism — unless it proceeds from mere accident or mutilation — may become hereditary or be the beginning of a new variety; it is only necessary, therefore, for the Weismannians to assume — as they are always ready to do — that any variation which has become fixed or permanent has already affected the germ. Their assumption needs only another assumption to prove it, and, therefore, when we are considering merely plain matters of fact and experience, we need give little attention to the subtleties of this Neo-Darwinian philosophy.

Weismann teaches that "acquired characters," or those variations which first appear in the lifetime of the individual because of the influences of environment, are lost, because they have not yet affected the reproductive substance. But if these characters are induced by the effect of impinging environment during two or more generations, they may come to be so persistent that the plant cannot throw them off, and they become, thereby, a part of the hereditary and non-negotiable property of the species. Now, it is apparent that in one or another of the generations which are thus acted upon by the environment, there must be a beginning towards the fixing or hereditable permanency of the new form, and we might as well assume that this beginning takes place in the first generation as in the last, since there can be no proof that it does not take place in either one. The tendency towards fixity, if it exists at all, undoubtedly originates at the very time that the variation itself originates, and it is only sophistry to assume that the form appears at one time and the tendency towards permanence at another time. Since plants fit themselves into their circumstances by means of adaptive variations, we must conclude that all adaptive variations have the power of persisting, upon occasion.

All these remarks, whilst somewhat abstruse, have a most important bearing upon the philosophy of the origin of garden varieties, because they show, first, that changes in the conditions in which plants grow introduce modifications in the plants themselves, and second, that wherever any modification occurs it is probable that it may be fixed and perpetuated.

It is necessary, at this point, that we distinguish between natal and post-natal variations; that is, between those variations which are born with plants, and those which appear, as a result of environment, after the plant has begun to grow. It is commonly assumed that the form and general characters of the plant are already determined in the seed, but a moment's reflection will show that this is far from the truth. One may sow a hundred selected peas, for instance, all of which may be alike in every discernible character. If these are planted in a space a foot square, it will be found, after two or three weeks, that some individuals are outstripping the others, although all of them came up equally well and were at first practically indistinguishable. This means that, because of a little advantage in food or moisture, or other circumstance, some plants have obtained the mastery and are crowding out the less fortunate ones. Here is a variation taking place before our very eyes, and we may be able to see the exact cause of it. Moreover, variations which originate in this way may pass down to the offspring through the seeds, as in the case of "viney" peas, which are grown on too rich soil. All this is a matter of the commonest observation with the gardener, who is so accustomed to seeing great differences arise in batches of plants, all of which start equal and with an equal chance, that he never thinks to comment upon the occurrence. In fact, the theory and practice of agriculture rest upon the fact that plants can be modified greatly by the conditions in which they grow, after they have become thoroughly established in the soil. Plants may start equal, but may differ widely at the harvest; and this difference may be controlled to a nicety by the cultivator. Every farmer knows, too, that the best results for the succeeding year are to be got only when he selects seeds from the best which he has been able to produce this year. So, given uniformity or equality at the start, the operator moulds the individual plants largely at his will.

Having noticed that physical environments may modify plants, we are now ready to consider just what changes in these circumstances of plant life are most fruitful in the production of new forms.

1. *Variation in Food Supply.* — The greater part of the changes in the physical conditions of life hinge upon the relative supply of food.

Climbing plants assume their form because, by virtue of the divergence of character, they are enabled to fit themselves into places which other plants cannot occupy. They rear their foliage into the air, where food and sunlight are unappropriated. The lower branches of the tree-top die, and the others thereby appropriate the more food and grow the faster. The entire practice of agriculture is built upon the augmentation of the food supply. For this purpose, we set the plants in isolated positions, we till the ground, keep down other plants or weeds, add plant food to the soil, and prune the tree and thin the fruit.

Thomas Andrew Knight, the chief of horticultural philosophers, appears to have been the first to clearly enunciate the law that excess of food supply is the most prolific cause of the variation of plants. Darwin subscribes to it without reserve: "Of all the causes which induce variability, excess of food, whether or not changed in nature, is probably the most powerful." Alexander Braun, an earlier philosophical writer on natural history, said that "it appears rather, on the whole, as if the unusual conditions favorable to a luxuriant state of development, afforded by cultivation, awakened in the plant the inward impulse to the display of all those variations possible within the more or less narrowly circumscribed limits of the species." It is generally agreed by those who have given the matter much thought, that an excess of food above the amount normally or habitually received is one of the very chief, if not the most dominant, causes of individual differences in plants. Certainly every farmer and gardener knows that the richer the soil in available plant food, the stronger and the more abnormal and unusual his product will be.

If, then, excess of food supply is a strong factor in the modification of plants, and if the one fundamental aim of agriculture is to supply food in excess of natural conditions, it must naturally follow that cultivated plants should be of all others the most variable. This is notably true. Now, the first variation which usually comes of this liberal food supply is increase in mere bigness. Probably every plant which has ever been cultivated has increased its stature or the size of some or all of its parts. Moreover, this is generally the direct object of cultivation, — to secure larger herbage, fruits, seeds, or flowers. Incidentally, we find here an indubitable proof of the truth of the hypothesis of evolution, for if it were impossible for plants to vary or to assume new characters, there would be no cultivation and no agriculture; for there would be little object in cultivating a product if it grew equally well in the wild.

This variation into mere bigness is more important than it may seem at first sight. All thoughtful horticulturists agree in believing that the first thing to be done in ameliorating any plant is to "break the type," that is, to cause it to vary. The particular direction of variation is not so important, at first; for all experience has shown that if once the seedlings of a plant begin to depart from the parental type, other and various modifications will soon follow. If a plant is once strongly modified in size, variations in shape, color, flavor, or other attributes are forthcoming. This apparent accumulation of variation seems at first to be incapable of scientific explanation, but the reasons for it are not difficult to understand when once they are presented.

When plants are placed in new conditions, whether in the wild or in cultivation, then they begin to vary, but usually only in one direction at first, although the amount of the variation, and sometimes the kind, is determined very largely by the nature and the extent of the change in the conditions. This initial variation, particularly when plants are transferred to cultivated areas, is generally in the direction of greater size consequent upon the greater amount of food. This initial variation is generally soon followed by others in various directions, and from these the cultivator may be able to establish new varieties. We now ask ourselves why these many variations appear when once the type begins to modify itself. Consider the fact that the world is now full of plants. In untamed nature, not one more plant can grow unless another plant dies. All plants, therefore, are held down to narrow limits of numbers, and since there are so few individuals, — in comparison with the seeds and buds which each plant produces for the chance of multiplying itself, — there must be, also, few kinds and degrees of individual differences. The farther and more freely a plant distributes itself, the greater must be the differences between the various individuals, because they must adapt themselves to a wider range of conditions. All plants are held in equilibrium, so to speak; but the plant organism is plastic by nature and quickly responds to every touch of environment; so, as soon as the pressure is removed in any direction, the plant at once springs into the breach. Recall the monotonous vegetation of the deep forest, where the battle of centuries has subdued all but the strongest. Clear away the forest, and then observe the fierce scramble for place and life amongst a multitude of forms which spring in for an opportunity to better their conditions. In a few years more, the tender low herbs have gone. The briars and underbrush have usurped the land. As time goes on, one species after another perishes, and when the place is again reforested, two or three species hold undisputed sway over the land. The poplars which followed the pines have long since perished and pines again dominate the forest. Or, if the area were turned to pasture a few years after the woods were removed, the herbs and bushes die with the browsing, and in time the June grass covers the whole landscape with the mantle of conquest. So plants may be said to be always ready to fill new places in the polity of nature by adapting themselves to the new circumstances as they grow into them. The appearing of any one marked variation, therefore, is evidence that the plant has found a new condition, that the pressure is somewhat lifted, and that its whole plastic organization will soon respond to the new environment. It is apparent, then, how the simplest and rudest cultivation has been able, through the centuries, to so profoundly modify our domestic plants that we are often unable to recognize the forms from which they sprung.

We must not forget to notice, at this point, that the food supply differs amongst the various branches of the same plant. Some branches, by reason of position with reference to the main trunk or with reference to air and sunlight, or, because of a better start in the beginning as a result of some incidental advantage, gain the mastery over others and crowd them out. We have already seen that no two branches on a plant are alike; and we are now able to understand that sports or bud-varieties are no more inexplicable than seed-varieties are.

Cultivation is really but an extension or intensification of nature's methods of dealing with the plant world. The ultimate object of both nature and man is to supply more food. The variations which arise from the effects of mere cultivation, therefore, are in kind very like those which nature produces, the chief difference being that of degree. The accustomed operations of the farmer, therefore, have been powerful agents in the evolution of vegetable forms. The ways in which cultivation affords a more liberal food supply are as follows: —

1. By isolating the individual plant. The husbandman sets each plant by itself, and then protects it by destroying the weeds or plants which endeavor to crowd it out. There is a partial exception to this in the "sowed crops," like the grains, and it is noticeable that variation in these plants is usually less marked than in the "hoed crops."

2. By giving the plant the advantage of position, whereby it is allowed the most congenial exposure to sun and contour of land.

3. By increasing the fertility of the soil, either by tillage or the direct application of plant

food, or both. Rich and moist soils tend to "break" the type, — or to cause initial variations, — to produce verdant colors and loss of saccharine and pungent qualities, to induce redundant growth, and to delay maturity and thereby to render plants tender to cold winter climates.

4. By thinning the tops of plants and the fruits, whereby the remaining parts receive an amount of food in excess of the habitual allowance.

5. By divergence of character in associated plants. It is well known that a field which is planted so thickly to corn that it cannot grow more with profit, may still grow pumpkins between. The pumpkins and the corn are so unlike in form that they complement each other, the one filling the niche which the other is not fitted to occupy. We have already seen that a copse ever so full of bushes may still grow vines. A meadow which is full of timothy may still grow clover in the bottom, and land which is covered with apple trees still grows weeds beneath. "The more diversified the descendants from any one species become in structure, constitution, and habits," writes Darwin, "by so much will they be better enabled to seize on many and widely diversified places in the polity of nature, and so be enabled to increase in numbers."

2. *Variation in Climate.* — The fact that any distinct climatic region usually has plants which are very closely related to those of other climatic regions in the same zone, points strongly to the probable profound modification of plants by climate. And, furthermore, we should expect that if the food environment modifies plants, the climatic environment must have the same power. Moreover, there is abundant historical and experimental proof that climate is capable of greatly modifying the vegetable kingdom. There are those who contradict any great effect of climate in the variation of plants, and acclimatization has been even stoutly denied. These persons make the mistake of asking that a visible modification take place at once upon the transfer of a plant from one climate to another, and they also err in supposing that a plant can adapt itself to a cold climate only by developing a capability to withstand more cold. Indian corn is sometimes cited as proof that plants do not become acclimatized, for it is as tender to frost now as ever, for all that we know. Yet this very plant affords a most unequivocal example of complete acclimatization, because it has shortened its period of growth fully one-half to enable it to escape the cold of the north.

The influence of a change of climate upon plants, or, what may amount to the same thing, the result of a transfer of plants to new climates, is so complex and so general that no detailed discussion of the subject can be made at this time. It will answer our present purpose to briefly designate the ways in which climate modifies plants: —

1. Climate greatly modifies the stature of plants. They become dwarfer in high latitudes and altitudes.

2. It modifies form. Plants tend to be broader-headed, and also more prostrate, in high latitudes and altitudes.

3. Proportionate leafiness generally increases, at the same time.

4. There is, also, often a gain in comparative fruitfulness following transfer towards the poles.

5. The colors of leaves, flowers, fruits, and seeds are greatly influenced by climate, there being a general tendency, in plants of temperate regions, to augmentation in intensity of colors as they are carried towards the poles.

6. There is modification in the flavor and essential ingredients of various parts, following a change of climate.

7. There is a variation in variability itself. The more difficult the climate in which a plant finds itself, the more it tends to vary to meet the uncongenial environments. In the high north, many plants are so variable that the marks used to identify the species in other latitudes are often lost.

8. There may be a profound variation or modification in constitution and habit by which plants become acclimatized, or enabled to endure a climate at first injurious to them. This may occur by a variation in the constitution of the descendants, which enables them to endure directly more untoward conditions. It generally comes about, however, through a change in habit, by which plants, when transferred towards the poles, shorten their season of growth or even become annuals. Plants become more sensitive to spring temperatures in cold climates, so that they start relatively much earlier in the season — that is, at a lower sum-temperature — than they do in warm climates. Any one who has passed the springtime in both the North and South must have noticed how much more suddenly the vegetation comes forward in the North; and it is surprising how the spring-sowed crops accelerate their growth in the North over those in the South.

The characters which result from a change of climatic environment are peculiarly within the control of the agriculturist, for a leading factor in his business is the transfer of plants far and wide over the earth. So it has come that the staple varieties of the important grains and fruits are unlike in Europe and America and in all great geographical areas, although all the various forms may have sprung from one ancestor within historic times. A new country is stocked with varieties from the mother country; but in the course of a few generations it is found that the varieties in cultivation are unlike the ones originally introduced, and from which they came. As wild plants have become separated from each other as species in the different geographical regions, so the cultivated plants soon begin to follow similar lines of divergence. In the beginning of the colonization of this country, for example, all the varieties of apples were of European origin. But in 1817, over sixty per cent of the apples recommended for cultivation here were of American origin, that is, American-grown seedlings from the original stock. At the present time, fully ninety per cent of the popular apples of the Atlantic states are American productions. The northern states of the Mississippi valley, to which most of our eastern apples are not adapted, are now witnessing a similar transformation in the adaptation and modification of the varieties introduced from the East and from Russia. The newly introduced Japanese plums are conceded to be great acquisitions to our fruit-growing, but no doubt the best results are yet to come with the origination of domestic varieties of them. So there is an irresistible tendency towards a divergence of forms in different continental or geographical regions, and much of the inevitable result is no doubt chargeable to climatic environment.

3. *Change of seed. Bud-variation.* — I will pause for a moment to consider two agencies or phenomena which are often associated with the genesis of varieties. One of these is the fact that the simple change of seed from one locality to another generally gives a larger or better product or even more marked variation. Mere transfer of seed is not of itself, however, a cause of variation. The change is beneficial because it fits together characters and environments which are not in equilibrium with each other. A plant which is grown for several years in one set of conditions becomes fitted into them, so to speak, and is in a comparative state of rest. When the plant or its progeny is taken to other conditions, all the adjustments are broken up, and in the refitting to the new circumstances new or strange characters are apt to appear. We shall leave this subject for the present, expecting to give it a fuller treatment in the second lecture.

Bud-variation, or sport, is a name given to those branches which are so much unlike the normal plant in any particular that they attract attention. Many garden varieties are simply multiplications of such abnormal branches. This bud-variation is commonly held to be such an unusual and inexplicable phenomenon that it is considered apart from all the general discussions of variation. It is not, of course, a cause of variability, but simply an effect of some antecedent, the same as seed-variation is. We have already seen that all the different branches, or even joints, of any plant are, in a very important sense, distinct individuals, since every one develops its own organs, each is capable of reproducing itself independently, and each is unlike every other because it is acted upon differently by environment and food supply. It is not strange, therefore, that some of these individuals should now and then depart very widely from the ordinary type, and thereby attract the attention of a gardener, who would forthwith make cuttings or set grafts from the part. Every branch is a bud-variety, just as truly as every seedling is a seed-variety, — since no seedling is ever exactly like its parent, — and there should be no greater mystery connected with the sports of buds than there is with the variations from seeds, for the causes which produce the one may be and are equally competent to produce the other.

d. *Struggle for Life a Cause of Variation.*

We have seen that the world is full of plants. There is room for more only as the present individuals die. Yet nearly every species produces a great number of seeds, and makes a most strenuous effort to multiply its kind. Any one plant, if left to itself, is capable of covering the earth in a comparatively short time. A fierce struggle for a chance to live is therefore inevitable. This conflict is most apparent to the general observer in the springtime, when every "herb yielding seed after his kind, and the tree yielding fruit, whose seed was in itself, after his kind," are sending forth a host of sturdy offspring. The very land seems to be pregnant with weeds and aspiring young growths. But by midsummer the numbers may be less. The weaker and less fortunate ones have perished, and the victors have waxed stronger thereby. The annual and half of the biennial species complete their course upon the approach of winter, and the older perennial herbs are becoming weak; so in the succeeding springtime there is again a fierce combat for the vacant places.

One of the results of this conflict is the adjustment of plants to each other. We have seen how the climbing plant insinuates itself in amongst the shrubberies and ties them together in an impenetrable tangle in order that it, itself, may have a chance to live. So the low plants of the deep forest are such as have been plastic enough to adapt themselves to the damp shades. Thus plants have developed companionships or divergences in characters, by means of which, under the stress of circumstances, they are able to live together. Plants have adapted themselves to other plants as truly as they have adapted themselves to soil or climate; and if these latter environments are ever the sources or causes of variation, then the first must be also. I must look upon the struggle for existence, therefore, as itself a cause of individual differences, since we know that any continued pressure from without awakens an adaptive response in the form of the vegetable organism.

III. THE CHOICE AND FIXATION OF VARIATIONS.

We have now seen that every living object is unlike every other. In plants, even every branch is unlike any other branch. We have endeavored to discover some of the causes of these universal differences. We have found that they are intimately associated with the welfare of the type or species, inasmuch as they appear, for the most part, to be the means of fitting the plant to live in the conditions in which it is placed. But we have also seen that there are more individuals than can find a place to live. How, then, does nature choose the best from the poorest, and, having chosen them, how does she endeavor to fix them, or to make them more or less stable?

"This preservation of favorable individual differences and variations, and the destruction of those which are injurious, I have called Natural Selection or the Survival of the Fittest." This is the philosophy which was propounded by Darwin, and which will carry his name to the last generation of men. It looks simple enough. Those forms which are best fitted to live, do live, because they crowd out the others. Yet, this simple principle of natural selection was the first explanation of the process of evolution which seemed to be capable of interpreting the complex phenomena of the forms of organic life. For a time, this philosophy was thought to be the one fundamental motive of the evolution or progression of life, but we are now convinced that there are other motives or forces at work; but it seems to be indisputable that natural selection is the chief force underlying the evolution of plants, and it is the only one with which the person who desires to breed plants need intimately concern himself.

We must now determine what a variety is. This is a vexed question, and one which seems never to be capable of an answer which is satisfactory to the gardener. Time and again, some person has introduced what he considered to be a distinct new variety, only to find that other horticulturists dispute him and declare that it is only some old variety renamed. And yet the introducer knows that he has not renamed an old variety, but that he has simply propagated a form which appeared or originated upon his own grounds.

Now, let us see. Nature starts out with the individual to make a new form. Every individual is unlike every other one. When the individual differences are so well marked that we can readily describe and distinguish them, and so permanent that they pass down nearly intact to a few generations, we say that we have a variety. If the differences are still more marked, we say that we have a species. Where the variety ends and the species begins it may be utterly impossible to determine ; so we mark off at a certain point and say, arbitrarily, that this much is variety and that much is species. Asa Gray once said to me that "species are judgments." Now, if there is no hard and fast line between the variety and the species, so there is none between the individual and the variety ; for a variety is only the family of descendants from some one individual. That is, the idea of variety or species rests upon difference, but just how much difference shall constitute one grade or another is a matter of individual opinion. So, when two gardeners cannot agree as to whether a given introduction is a new variety or not, they are having just the same difficulty that two botanists have when they cannot decide whether two plants are two species or one.

It is apparent, then, that every individual plant is a distinct variety, only that the differences between it and other individuals may be so slight that they have no practical utility and cannot be described and recorded. Just as soon as an individual plant has characters so unlike its kin that it has some commercial value, then the plant will be increased by cuttings or grafts or seeds, the brood of offspring will be given a name, and a new variety is born.

Individuals with the same general features may appear simultaneously in two or more places, and two or more men may propagate, name, and introduce them. When they are all brought together and compared, it will be said that they are all the same variety, that, according to the rules of nomenclature, the brood which chanced to be named first must "stand" or be held to be the type of the variety, and that the other names must become synonyms. Yet some person may discover minor differences in them and demand that the varieties be kept distinct. So the see-saw goes on — a variety is a variety so long as it answers some purpose in use or trade, and it is not a variety when it is so much like some other variety that it has no merit which the other does not possess.

As soon as a plant appears with some feature which is more desirable than anything which has preceded it, therefore, it may be made the beginning of a new variety. Man chooses it, and then propagates it. This is human selection. If nature did the same, it would be natural selection.

Now, how does nature preserve or fix this type? She does not preserve it! She simply chooses it as a beginning and gradually modifies it and shapes it into the form which she needs. She has no permanent forms. There is a general onward progression of every type either towards other types or towards extinction. We have seen that nature is constantly choosing and selecting. If she selects an individual for the beginning of a race, then she selects just as keenly from every offspring of that individual, and so on to the end of time. The process never stops. So nature fixes her forms by keeping them moving, growing, constantly developing farther away from their beginnings.

Now, man does the same thing. A plant in a cabbage row pleases him. It has a solid, small head and stout stem. He stores it away for seed. Amongst the offspring, perhaps fifty per cent are as good as the parent. These are saved. So the process goes on, from season to season. In four or five generations of plants, he finds that ninety per cent of the seeds "come true." Then he names it and introduces it. It is well advertised in the seed catalogues. Many people buy the seeds. Some of these persons will grow their own seed, and every one of them has a different ideal in mind when selecting the seed parents. So, in the course of a few years, it is found that there are really several more or less different forms going under the same name. Some person may observe this difference and legitimately introduce one or more of the forms as distinct varieties. Some other person, however, who has known the history of the stock and who is not aware that varieties pass into other forms, objects to the new names and declares that the introducer is imposing upon the public.

This is the history of ninety-nine out of every hundred varieties which are habitually propagated by seeds, like the kitchen-garden vegetables and the annual flowers. Some peculiar individual, appearing we know not why, is discovered, and seeds are saved and selection — perhaps unconscious selection — begins. After a time the variety is broken up into several, or else, if it varies only slightly into divergent forms, the whole body or generations of the variety move onward, gradually departing from the initial type until it is no longer the same, although it may still bear the same name. The life of seed-varieties, in their pure and original form, is very short. Even the best of them are usually measured by one or two decades. They run out or pass out by variation, into other forms. The Trophy tomato is not the Trophy tomato which was introduced over twenty years ago, although it bears the old name and is a direct descendant of the first stock.

In plants multiplied by buds — that is, by budding, grafting, cuttings, tubers, and the like — there is less variation in the offspring than in those propagated by seeds. Yet we have seen that no two Baldwin apple trees — all of which are but divisions, more or less remote, of the one original tree — are alike, and now and then one branch of a fruit tree may "sport," or develop a strange bud-variety. We know, too, that the same variety of fruit tree takes on different characters in different geographical regions, so that the Greening apple is no longer the Greening of Rhode Island in the West and South. So, it is apparent that even when we divide a plant into many parts and distribute the members far and wide, and when there is no occasion for concerning ourselves with fixing the type, — even here there is variation. In some cases, particularly in those in which we multiply the plant by dividing abnormally developed parts, there is a tendency to scatter or to vary in many directions, and also a tendency to run out by degeneration. This is admirably true of the potato, varieties of which, in ten years or less, become so mixed in their characters, through rapid variation and deterioration, that we must return to seedling productions for a new start.

Man is only rarely the direct means of originating variations. He finds them amongst the normal plants of the field and garden. His skill and science are exercised in the selection and so-called breeding of the offspring, more than in the original genesis of the new form. It is usually only in those plants which he multiplies by simple division that he gains much direct profit by crossing or hybridizing. It is the slow and patient care and selection, day by day, which permanently ameliorate and improve the vegetable world. Nature starts the work; man may complete it.

It is now generally believed that species in nature sometimes originate suddenly, by means of "leaps." In fact, the recent De Vriesian view is that real species so originate, and the steps whereby a new species comes into existence are called mutations (see Lecture IV.). However this may be, it is nevertheless true that these mutations are yet beyond the power of man directly to produce. Selection is still a powerful agent with which to ameliorate domestic plants.

LECTURE II.

THE PHILOSOPHY OF THE CROSSING OF PLANTS, CONSIDERED IN REFERENCE TO THEIR IMPROVEMENT UNDER CULTIVATION.

I. The Struggle for Life.

It is now understood that the specific forms or groups of plants have been determined largely by the survival of the fittest in a long and severe struggle for existence. The proof that this struggle everywhere exists becomes evident upon a moment's reflection. We know that all organisms are eminently variable. In fact, no two plants or animals in the world are exactly alike. We also know that very few of the whole number of seeds which are produced in any area ever grow into plants. If all the seeds produced by the elms upon Boston Common in any fruitful year were to grow into trees, this city would become a forest as a result. If all the seeds of the rarest orchid in our woods were to grow, in a few generations of plants even our farms would be overrun. If all the rabbits which are born were to reach old age, and all their offspring were to do the same, in less than ten years every vestige of herbage would be swept from the country, and our farms would become barren. There is, then, a wonderful latent potency in these species; but the same may be said of every species of plant and animal, even of man himself. If one species of plant would overrun and usurp the land if it increased to the full extent of its possibilities, what would be the result if each of the two thousand and sixty-one plants known to inhabit Middlesex County were to do the same? And then fancy the result if each of the animals, from rabbits and mice to frogs and leeches, were to increase without check! The plagues of Egypt would be insignificant in the comparison!

The fact is, the world is not big enough to hold the possible first offspring of the plants and animals at this moment living upon it. Struggle for existence, then, is inevitable, and it must be severe. It follows as a necessity that those seeds grow or those plants live which are best fitted to grow and live, or which are fortunate enough to find a congenial foothold. It would appear, at first thought, that much depends upon the accident of falling into a congenial place, or one unoccupied by other plants or animals; but, inasmuch as scores of plants are contending for every unoccupied place, it follows that everywhere only the fittest can germinate or grow. In the great majority of cases, plants grow in a certain place because they are better fitted to grow there, to hold their own, than any other plants are; and the instances are rare in which a plant is so fortunate as to find an unoccupied place. We are apt to think that plants chance to grow where we find them, but the chance is determined by law, and therefore is not chance.

Much of the capability of a plant to persist under all this struggle depends, therefore, upon how much it varies; for the more it varies the more likely it is to find places of least struggle. It grows under various conditions, — in sun and shade, in sand and clay, by the sea-shore or upon the hills, in the humidity of the forest or the aridity of the plain. In some directions it very likely finds less struggle than in others, and in these directions it expands itself, multiplies, and gradually dies out in other directions. So it happens that it tends to take on new forms, or to undergo an evolution. In the meantime, all the intermediate forms, which are at best only indifferently adapted to their conditions, tend to disappear. In other words, gaps appear which we call "missing links." The weak links break and fall away, and what was once a chain becomes a series of rings. So the "missing links" are amongst the best proofs of evolution.

The question now arises as to the cause of these numerous variations in animals and plants. Why are no two individuals in nature exactly alike? The question is exceedingly difficult to answer.

It was once said that plants vary because it is their nature to vary; that variation is a necessary function, as much as growth or fructification. This really removes the question beyond the reach of philosophy; and direct observation leads us to think that some variation, at least, is due to external circumstances. (See Lecture I.) We are now looking for the cause of variation as a part of the scheme of evolution; and we are wondering if the varied surroundings, or, as Darwin put it, the "changed conditions of life," may not actually induce variability. This conclusion would seem to follow from the fact of the severe and universal struggle in nature whereby plants are constantly forced into new and strange conditions. But there is undoubtedly much variation which has sprung from more remote causes, one of which it is my purpose to discuss here.

II. The Division of Labor.

In the lowest animals and plants — which are simply single cells — the species multiplies by means of simple division or by budding. One individual, of itself, becomes two, and the two are therefore recasts of the one. But, as organisms multiplied and conditions became more complex, that is, as struggle increased, there came a differentiation in the parts of the individual, so that one cell or one cluster of cells performed one labor and other cells performed other labor; and this tendency resulted in the development of organs. Simple division, therefore, might no longer reproduce the whole complex individual; and, as all organs are necessary to the existence of life, the organism may die if it is divided. Along with this specialization came the differentiation into sex; and sex clearly has two offices: to hand over, by some mysterious process, the complex organization of the parent to the offspring, and also to unite the essential characters or tendencies of two beings into one. The second office is manifestly the greater, for, as it unites two organizations into one, it insures that the offspring is somewhat unlike either parent, and is therefore better fitted to seize upon any place or condition new to its kind. And as the generations increase, the tendency to variation in the offspring may be constantly greater, because the impressions of a greater number of ancestors are transmitted to it. I have said that this office of sex to induce variation is more important than the mere fact of reproduction of a complex organization; for it must be borne in mind that the complexity of organization is itself a variation and adaptation made necessary by the increasing struggle for existence.

If, therefore, the philosophy of sex is to promote variation by the union of different individuals, it must follow that the greatest variation must come from parents considerably unlike each other in their minor characters. Thus it comes that inbreeding tends to weaken a type, and cross-breeding tends to strengthen it. And at this point we meet the particular subject which I am to present to you. I have introduced you to this preliminary sketch because I contend that we can understand crossing only as we make it a part of the general philosophy of nature. There are the vaguest notions concerning the possibilities of crossing, some of which I hope to correct by presenting the subject in its relations to the general aspects of the vegetable world.

We are now prepared to understand that crossing is good for the species, because it constantly revitalizes offspring with the strongest traits of the parents, and ever presents new combinations which enable the individuals to stand a better chance of securing a place in the polity of nature. The further discussions of the subject are such as have to do with the extent to which crossing is possible and advisable, and the general results of the operation.

III. The Limits of Crossing.

If crossing is good for the species, which philosophy and direct experiment abundantly show, it is necessary at once to find out to what extent it can be carried. Does the good increase in proportion as the cross becomes more violent, or as the parents are more and more unlike? Or do we soon find a limit beyond which it is not profitable or even possible to go,—a point at which we say that "an inch is as good as an ell"? If great variability is good for the species in the struggle for existence, and if crossing induces variability because of the union of unlike individuals, it would seem to follow that the more unlike the parents are, the greater will be the variation in offspring and the more the type will prosper; and, carrying this thought to its logical conclusion, we should expect to find that the most closely related plants would constantly tend to refuse to cross, because the offspring of them would be little variable and therefore little adapted to the struggle for existence; while the most widely separated plants would constantly tend to cross more and more, because their offspring would present the greatest possible degrees of differences. We should expect, for instance, that a Baldwin apple would be less likely to cross with a Greening than it is to cross with a peach or a gourd. And, if we should carry our thought a step farther, we should at once see that this crossing between different species would soon fill in all differences between those species, and that definite specific types would cease to exist. This would be pandemonium, and crossing would be the cause of it!

Now, essentially this reasoning has been advanced to combat the evolution of plants and animals by means of natural selection; and this proposition that intermixing must constantly tend to obliterate all differences between plants and to prevent the establishment of well-marked types, has been called the "swamping effects of intercrossing." It is exceedingly important that we consider this question, for it really lies at the foundation of the improvement of cultivated plants by means of crossing, as well as the persistence and evolution of varieties and species under wholly natural conditions.

We find, however, that distinct species, as a rule, refuse to cross; and the first question which naturally arises is, What is the immediate cause of the refusal of plants to cross? How does this refusal express itself? It comes about in many ways. The commonest cause is the positive refusal of a plant to allow its ovules to be impregnated by the pollen of another plant. The pollen will not "take." For instance, if we apply the pollen of a Hubbard squash to the flower of the common field pumpkin, there will simply be no result, — the fruit will not form. The same is true of the pear and the apple, the oat and the wheat, and most very unlike species. Or the refusal may come in the sterility of the cross or hybrid: the pollen may "take" and seeds may be formed and the seeds may grow, but the plants which they produce may be wholly barren, sometimes even refusing to produce flowers as well as seeds, as in the instance of some hybrids between the Wild Goose plum and the peach. Sometimes the refusal to cross is due to some difference in the time of blooming or some incompatibility in the structure of the flowers. But it is enough for our purpose to know that there are certain characters in widely dissimilar plants which prevent intercrossing, and that these characters are just as positive and just as much influenced by change of environment and natural selection as are size, color, productiveness, and other characters.

Here, then, is the sufficient answer to the proposition that intercrossing must swamp all natural selection, and also the explanation of the varying and often restricted limits within which crossing is possible. That is, the checks to crossing have been developed through the principle of universal variability and natural selection, as has been shown by Darwin and Wallace. Plants vary in their reproductive organs and powers just the same as they do in other directions; and when such a variation is useful it is perpetuated, and when hurtful it is lost. Suppose that a certain well-marked individual of a species should find an unusually good place in nature, and it should multiply rapidly. Crosses would be made between its own offspring and perhaps between those offspring and itself in succeeding years; and it is fair to suppose that some of the crosses would be particularly well adapted to the conditions in which the parent grew, and these would constantly tend to perpetuate themselves, while less adaptive forms would constantly tend to disappear. Now, the same thing would take place if this individual or its adaptive offspring were to cross with the main stock of the parent species; for all the offspring of such a cross which is intermediate in character and therefore less adapted to the new conditions would tend to disappear, and the two types would, as a result, become more and more fixed and the tendency to cross would constantly decrease.

The refusal to cross, therefore, becomes a positive character of separation, and the "missing links" which result from crossing are no more or no less inexplicable than the "missing links" due to simple selection; or, to put the case more accurately, natural selection weeds out the tendency to promiscuous crossing, when it is hurtful, in just the same manner that it weeds out any other injurious tendency. It makes no difference in what way this tendency expresses itself, whether in some constitutional refusal to cross, — if such exists, — or in infertility of offspring, or in different times of blooming: all equally come under the power of natural selection. We are apt to look upon infertility as the absence of a character, a sort of a negative feature which is somehow not the legitimate property of natural selection; but such is not the case. We are perhaps led the more to this feeling because the word infertility is itself negative, and because we associate full productiveness with the positive attributes of plants. But loss of productiveness is surely no more a subject of wonder than loss of color or size, if there is some corresponding gain to be accomplished. In fact, we see, in numerous plants which propagate easily by means of runners and suckers, a very low degree of productiveness, that is, infertility.

Now, if this reasoning is sound, it leads us to conclusions quite the reverse of those held by the advocates of the swamping effects of intercrossing, and these conclusions are of the most vital importance to every man who tills the soil. The logical result is simply this: the best results of crossing are obtained, as a rule, when the cross is made between different individuals of the same variety, or at farthest, between different individuals of the same species. In other words, hybrids — or crosses between species — are rarely useful in nature, and it follows that the more unlike the species the less useful will be the hybrids. This, I am aware, is counter to the notions of most horticulturists, and, if true, must entirely overthrow our common thinking upon this subject. But I think that I shall be able to show that observation and experiment lead to the same conclusion to which our philosophy has brought us.

IV. Function of the Cross.

a. *The Gradual Amelioration of the Type.*

At this point we must ask ourselves what we mean by "best results." I take this phrase to refer to those plants which are best fitted to survive in the struggle for existence, those which are most vigorous or most productive or most hardy, or which possess any well-marked character or characters which distinguish them in virility from their fellows. We commonly associate the term more particularly with marked vigor and productiveness; these are the characters most useful in nature and also in cultivation, the ones which we oftenest desire to obtain. Another type of variation which we constantly covet is something which we can call a new character, which will lead to the production of a new cultural variety, and we are always looking to this as the legitimate result of crossing. We have forgotten — if, indeed, we ever knew — that the commoner, all-pervading, more important function of the cross is to infuse some new strength or power into the offspring, to improve or to perpetuate an existing variety, rather than to create a new one. Or, if a new one is created, it comes from the gradual passing of one into another, an inferior variety into a good one, a good one into a superlative one. So nature employs crossing in a process of slow or gradual improvement, one step leading to another, and not in any bold or sudden creation of new forms. And there is evidence to show that something akin to this must be done to secure the best and most permanent results under cultivation. The notion is somehow firmly rooted in the popular mind that new varieties can be produced with the greatest ease by crossing parents of given attributes. There is something captivating about the notion. It smacks of a somewhat magic power which man evokes as he passes his wand over the untamed forces of nature. But the wand is often only a gilded stick, and is apt to serve no better purpose than the drum major's pretentious baton?

Let me say further that crossing alone can accomplish comparatively little. The chief power in the evolution or progression of plants appears to be selection, or, as Darwin puts it, the law of "preservation of favorable individual differences and variations, and the destruction of those which are injurious." Selection is the force which augments, develops, and fixes types. Man must not only practice a judicious selection of parents from which the cross is to come, which is in reality but the exercise of a choice, but he must constantly select the best from among the crosses, in order to maintain a high degree of usefulness and to make any advancement; and it sometimes happens that the selection is much more important to the cultivator than the crossing. I do not wish to discourage the crossing of plants, but I do desire to dispel the charm which too often hangs about it.

Further discussion of this subject naturally falls under two heads: the improvement of existing types or varieties by means of crossing, and the summary production of new varieties. I have already stated that the former office is the more important one, and the proposition is easy of proof. It is the chief use which nature makes of crossing, — to strengthen the type. Think, for instance, of the great rarity of hybrids or pronounced crosses in nature. No doubt all the authentic cases on record could be entered in one or two volumes, but a list of all the individual plants of the world could not be compressed into ten thousand volumes. There are a few genera, in which the species are not well defined or in which some character of inflorescence favors promiscuous crossing, in which hybrids are conspicuous; but even here the number of individual hybrids is very small in comparison to the whole number of individuals. That is, the hybrids are rare, while the parents may be common. This is well illustrated even in the willows and oaks, in which, perhaps, hybrids are better known than in any other American plants. The great genus carex or sedge, which occurs in great numbers and many species in almost every locality in New England, and in which the species are particularly adapted to intercrossing by the character of their inflorescence, furnishes but few undoubted hybrids. Among one hundred and eighty-five species and prominent varieties inhabiting the northeastern states, there are only eleven hybrids recorded, and all of them are rare or local, some of them having been collected but once. Species of carex of remarkable similarity may grow side by side for years, even intertangled in the same clump, and yet produce no hybrid. These instances prove that nature avoids hybridization, — a conclusion at which we have already arrived from philosophical considerations. And we have reason to infer the same conclusion from the fact that flowers of different species are so constructed as not to invite intercrossing. But, on the other hand, the fact that all higher plants habitually propagate by means of seeds, which is far the most expensive to the plant of all methods of propagation, while at the same time most flowers are so constructed as to prevent self-fertilization, proves that some corresponding good must come from crossing within the limits of the species or variety; and there are purely philosophical reasons, as we have seen, which warrant a similar conclusion.

But experiment has given us more direct proof of our propositions, and we shall now turn our attention to the garden.

Darwin was the first to show that crossing within the limits of the species or variety results in a constant revitalizing of the offspring, and that this is the particular ultimate function of cross-fertilization. Kölreuter, Sprengel, Knight, and others had observed many, if, indeed, not all, the facts obtained by Darwin; but they had not generalized upon them broadly, and did not conceive their relation to the complex life of the vegetable world. Darwin's results are, concisely, these; self-fertilization tends to weaken the offspring; crossing between different plants of the same variety gives stronger and more productive offspring than arises from self-fertilization; crossing between stocks of the same variety grown in different places or under different conditions gives better offspring than crossing between different plants grown in the same place or under similar conditions; and his researches have also shown that, as a rule, flowers are so constructed as to favor cross-fertilization. In short, he found, as he expressed it, that "nature abhors perpetual self-fertilization." Some of his particular results, although often quoted, will be useful in fixing these facts in our minds. Plants from crossed seeds of morning-glory exceeded in height those from self-fertilized seeds as 100 exceeds

76, in the first generation. Some flowers from these plants were self-pollinated and some were crossed, and in this second generation the crossed plants were to the uncrossed as 100 is to 79; the operation was again repeated, and in the third generation the figures stand 100 to 68; fourth generation, the plants having been grown in midwinter, when none of them did well, 100 to 86; fifth generation, 100 to 75; sixth generation, 100 to 72; seventh generation, 100 to 81; eighth generation, 100 to 85; ninth generation, 100 to 79; tenth generation, 100 to 54. The average total gain in height of the crossed over the uncrossed was as 100 to 77, or about 30 per cent. There was a corresponding gain in fertility, or the number of seeds and seed-pods produced. Yet, striking as the results are, they were produced by simply crossing between plants grown near together, and under what would ordinarily be called uniform conditions. In order to determine the influence of crossing with fresh stock, plants of the same variety were obtained from another garden, and these were crossed with the ninth generation mentioned above. The offspring of this cross exceeded those of the other crossed plants as 100 exceeds 78, in height; as 100 exceeds 57, in the number of seed-pods; and as 100 exceeds 51, in the weight of the seed-pods. In other words, crosses between fresh stock of the same variety were nearly 30 per cent more vigorous than crosses between plants grown side by side for some time and over 44 per cent more vigorous than plants from self-fertilized seeds. On the other hand, experiments showed that crosses between different flowers upon the same plant gave actually poorer results than offspring of self-fertilized flowers. It is evident, from all these figures, that nature desires crosses between plants, and, if possible, between plants grown under somewhat different conditions. All the results are exceedingly interesting and important; and there is every reason to believe that, as a rule, similar results can be obtained with all plants.

Darwin extended his investigations to many plants, only a few of which need be discussed here. Cabbage gave pronounced results. Crossed plants were to self-fertilized plants in weight as 100 is to 37. A cross was now made between these crossed plants and a plant of the same variety from another garden, and the difference in weight of the resulting offspring was the difference between 100 and 22, showing a gain of over 350 per cent, due to a cross with fresh stock. Crossed lettuce plants exceeded uncrossed in height as 100 exceeds 82. Buckwheat gave an increase in weight of seeds as 100 to 82, and in height of plants as 100 to 69. Beets gave an increase in height represented by 100 and 87. Maize, when full grown, from crossed and uncrossed seeds, gave the differences in height between 100 and 91. Canary-grass gave similar results.

I have obtained results as well marked as these upon a large and what might be called a commercial scale. I raised the plants during the first generation of seeds from known parentage, the flowers from which they came having been carefully pollinated by hand. In some instances the second generations were grown from hand-crossed seeds, but in other cases the second generations were grown from seeds simply selected from the first-year patches. As the experiments have been made in the field and upon a somewhat extensive scale, it was not possible to accurately measure the plants and the fruits from individuals in all cases; but the results have been so marked as to admit of no doubt as to their character. In 1889 several hand-crosses were made among egg-plants. Three fruits matured, and the seeds from them were grown in 1890. Some two hundred plants were grown, and they were characterized throughout the season by great sturdiness and vigor of growth. They grew more erect and taller than other plants near by grown from commercial seeds. They were the finest plants which I had ever seen. It was impossible to determine productiveness, from the fact that our seasons are too short for egg-plants, and only the earliest flowers, in the large varieties, perfect their fruit, and the plant blooms continuously through the season. In order to determine how much a plant will bear, it must be grown until it ceases to bloom. When frost came, I could see little difference in productiveness between these crossed plants and commercial plants. A dozen fruits were selected from various parts of this patch, and in 1891 about twenty-five hundred plants were grown from them. Again the plants were remarkably robust and healthy, with fine foliage, and they grew erect and tall, — an indication of vigor. They were also very productive; but, as the cross had been made between unlike varieties, and the offsprings were therefore unlike either parent, I could not make an accurate comparison. But they compared well with commercial egg-plants, and I am satisfied that they would have shown themselves to be more productive than common stock could they have grown a month or six weeks longer. Professor Munson, of the Maine Agricultural College, grew some of this crossed stock in 1891, and he told me that it was better than any commercial stock in his gardens.

In extended experiments in the crossing of pumpkins, squashes, and gourds, carried on during several years, increase in productiveness due to crossing has been marked in many instances. Marked increase in productiveness has been obtained from tomato crosses, even when no other results of crossing could be seen.

b. *Change of Seed and Crossing.*

Bearing in mind these good influences of crossing, let us recall another series of facts following the simple change of seed. Almost every farmer and gardener at the present day feel that an occasional change of seed results in better crops, and there are definite records to show that such is often the case. In fact, I am convinced that much of the rapid improvement in fruits and vegetables in recent years is due to the practice of buying plants and seeds so largely of dealers, by means of which the stock is often changed. Even a slight change, as between farms or neighboring villages, sometimes produces marked results, such as more vigorous plants and often more fruitful ones. We must not suppose, however, that because a small change gives a good result, a violent or very pronounced change gives a better one. There are many facts on record to show that great changes often profoundly influence plants, and when such influence results in lessened vigor or lessened productiveness we call it an injurious one. Now, this injurious influence may result even when all the conditions in the new place are favorable to the health and development of the plant; it is an influence which is wholly independent, so far as we can see, of any condition which interferes injuriously with the simple processes of growth. Seeds of a native physalis or husk-tomato were sent to me from Paraguay in 1889 by Dr. Thomas Morong, then travelling in that country. I grew it from cuttings in the house and out of doors, and for two generations was unable to make it set fruit, even though the flowers were hand-pollinated; yet the plants were healthy and grew vigorously. The third cutting-generation grown out of doors set fruit freely. This is an instance of the fact that very great changes of conditions may injuriously affect the plant, and an equally good illustration of the power to overcome these conditions. Now, there is great similarity between the effects of slight and violent changes of conditions and small and violent degrees of crossing, as both Darwin and Wallace have pointed out, and it is pertinent to this discussion to endeavor to discover why this similarity exists.

It is well proved that crossing is good for the resulting offspring, because the differences between the parents carry over new combinations of characters or at least new powers into the crosses. It is a process of revitalization, and the more different the stocks in desirable characters within the limits of the variety, the greater is the revitalization; and frequently the good is of a more positive kind, resulting in pronounced characters which may serve as the basis for new varieties. In the cross, therefore, a new combination of characters or a new power fit it to live better than its parents in the conditions under which they lived.

In the case of change of stock we find just the reverse, which, however, amounts to the same thing, — that the same characters or powers fit the plant to live better in conditions new to it than plants which have long lived in those conditions. In either case, the good comes from the fitting together of new characters or powers and new environments. Plants which live during many generations in one place become accustomed to the place, thoroughly fitted into its conditions, and are in what Mr. Spencer calls a state of equilibrium. When either plant or conditions change, new adjustments must take place; and the plant may find an opportunity to take advantage, to expand in some direction in which it has before been held back; for plants always possess greater power than they are able to express. "These rhythmical actions or functions [of the organism]," writes Spencer, "and the various compound rhythms resulting from their combinations, are in such adjustment as to balance the actions to which the organism is subject. There is a constant or periodic genesis of forces which, in their kinds, amounts, and directions, suffice to antagonize the forces which the organism has constantly or periodically to bear. If, then, there exists this state of moving equilibrium among a definite set of internal actions, exposed to a definite set of external actions, what must result if any of the external actions are changed? Of course there is no longer an equilibrium. Some force which the organism habitually generates is too great or too small to balance some incident force; and there arises a residuary force exerted by the environment on the organism, or by the organism on the environment. This residuary force, this unbalanced force, of necessity expends itself in producing some change of state in the organism."

The good results, therefore, are processes of adaptation, and when adaptation is perfectly complete the plant may have gained no permanent advantage over its former condition, and new crossing or another change may be necessary; yet there is often a permanent gain, as when a plant becomes visibly modified by change to another climate. Now, this adaptive change may express itself in two ways: either by some direct influence upon the stature, vigor, or other general character, or indirectly upon the reproductive powers, by which some new influence is carried to the offspring. If the direct influences become hereditary, as observation seems to show may sometimes occur, the two directions of modification may amount, ultimately, to the same thing.

For the purposes of this discussion it is enough to know that crossing within the variety and change of stock within ordinary bounds are beneficial, that the results in the two cases seem to flow from essentially the same causes, and that crossing and change of stock combined give much better results than either one alone; and this benefit is expressed more in increased yield and vigor than in novel and striking variations. These processes are much more important than any mere groping after new varieties, as I have already said; not only because they are surer, but because they are universal and necessary means of maintaining and improving both wild and cultivated plants. Even after one succeeds in securing and fixing a new variety, he must employ these means to a greater or less extent to maintain fertility and vigor, and to keep the variety true to its type. In the case of some garden crops, in which many seeds are produced in each fruit and in which the operation of pollination is easy, actual hand-crossing from new stock now and then may be found to be profitable. But in most cases the operation can be left to nature, if the new stock is planted among the old. Upon this point Darwin expressed himself as follows: "It is a common practice with horticulturists to obtain seeds from another place having a very different soil, so as to avoid raising plants for a long succession of generations under the same conditions; but with all the species which freely intercross by the aid of insects or the wind, it would be an incomparably better plan to obtain seeds of the required variety, which had been raised for some generations under as different conditions as possible, and sow them in alternate rows with seeds matured in the old garden. The two stocks would then intercross, with a thorough blending of their whole organizations, and with no loss of purity to the variety, and this would yield far more favorable results than a mere change of seed."

c. *The Outright Production of New Varieties.*

But you are waiting for a discussion of the second of the great features of crossing, — the summary production of new varieties. This is the subject which is almost universally associated with crossing in the popular mind, and even among horticulturists themselves. It is the commonest notion that the desirable characters of given parents can be definitely combined in a pronounced cross or hybrid. There are two or three philosophical reasons which somewhat oppose this doctrine, and which we will do well to consider at the outset. In the first place, nature is opposed to hybrids, for species have been bred away from each other in the ability to cross. If, therefore, there is no advantage for nature to hybridize, we may suppose that there would be little advantage for man to do so; and there would be no advantage for man did he not place the plant under conditions different from nature, or desire a different set of characters. We have seen that nature's chief barriers to hybridization are total refusal of species to unite, and entire or comparative seedlessness of offspring. We can overcome the refusal to cross in many cases by bringing the plant under cultivation; for the character of the species becomes so changed by the wholly new conditions that its former antipathies may be overpowered. Yet it is doubtful if such a plant will ever acquire a complete willingness to cross. In like manner we can overcome in a measure the comparative seedlessness of hybrids, but it is very doubtful whether we can ever make such hybrids completely fruitful. It would appear, therefore, on theoretical grounds, that in plants in which seeds are the part sought, no permanent practical good can be expected, as a rule, from hybridization.[1]

It is evident that species which have been differentiated or bred away from each other in a given locality will have more opposed qualities or powers than similar species which have arisen quite independently in places remote from each

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[1] See definition of hybrids, crosses, and other terms in the Glossary.

other. In the one case the species have likely struggled with each other until each one has attained to a degree of divergence which allows it to persist; while in the other case there has been no struggle between the species, but similar conditions have brought about similar results. These similar species which appear independently of each other in different places are called representative species. Islands remote from each other but similarly situated with reference to climate very often contain representative species; and the same may be said of other regions much like each other, as eastern North America and Japan. Now, it follows that, if representative species are less opposed than others, they are more likely to hybridize with good results; and this fact is remarkably well illustrated in the Kieffer and allied pears, which are hybrids between representative species of Europe and Japan; and I am inclined to think that the same may be found to be true of the common or European apple and the wild crab of the Mississippi valley. Various crabs of the Soulard type, which I once thought to constitute a distinct species, appear upon further study to be hybrids. We will also recall that the hybrid grapes which have so far proved most valuable are those obtained by Rogers between the American Vitis Labrusca and the European wine grape; and that the attempts of Haskell and others to hybridize associated species of native grapes have given, at best, only indifferent results. To these good results from hybrids of fruit trees and vines I shall revert presently.

Another theoretical point, which is borne out by practice, is the conclusion that, because of the great differences and lack of affinity between parents, pronounced hybrid offsprings are unstable. This is one of the greatest difficulties in the way of the summary production of new varieties by means of hybridization. It would appear, also, that, because of the unlikeness of parents, hybrid offspring must be exceedingly variable; but, as a matter of fact, in many instances the parents are so pronouncedly different that the hybrids represent a distinct type by themselves, or else they approach very nearly to the characters of one of the parents. There are, to be sure, many instances of exceedingly variable hybrid offspring, but they are usually the offspring of variable parents. In other words, variability in offspring appears to follow rather as a result of variability in parents than as a result of mere unlikeness of characters. But the instability of hybrid offspring when propagated by seed is notorious. Wallace writes that "the effect of occasional crosses often results in a great amount of variation, but it also leads to instability of character, and is therefore very little employed in the production of fixed and well-marked races." I may remark again that, because of the unequal and unknown powers of the parents, we can never predict what characters will appear in the hybrids. This fact was well expressed by Lindley a half century ago, in the phrase, "Hybridizing is a game of chance played between man and plants."

V. CHARACTERISTICS OF CROSSES.

Bearing these fundamental propositions in mind, let us pursue the subject somewhat in detail. We shall find that the characters of hybrids, as compared with the characters of simple crosses between stocks of the same variety, are ambiguous, negative, and often prejudicial. The fullest discussion of hybrids has been made by Focke (see Lecture IV.), and he lays down the five following propositions concerning the character of hybrid offspring: —

1. "All individuals which have come from the crossing of two pure species or races, when produced and grown under like conditions, are usually exactly like each other, or at least scarcely more different from each other than plants of the same species are." This proposition, although perhaps true in the main, appears to be too broadly and positively stated.

2. "The characters of hybrids may be different

from the characters of the parents. The hybrids differ most in size and vigor and in their sexual powers."

3. "Hybrids are distinguished from their parents by their powers of vegetation or growth. Hybrids between very different species are often weak, especially when young, so that it is difficult to raise them. On the other hand, cross-breeds are, as a rule, uncommonly vigorous; they are distinguished mostly by size, rapidity of growth, early flowering, productiveness, longer life, stronger reproductive power, unusual size of some special organs, and similar characteristics."

4. "Hybrids produce a less amount of pollen and fewer seeds than their parents, and they often produce none. In cross-breeds this weakening of the reproductive powers does not occur. The flowers of sterile or nearly sterile hybrids usually remain fresh a long time."

5. "Malformations and odd forms are apt to appear in hybrids, especially in the flowers."

Some of the relations between hybridization and crossing within narrow limits are stated as follows by Darwin: "It is an extraordinary fact that with many species flowers fertilized with their own pollen are either absolutely or in some degree sterile; if fertilized with pollen from another flower on the same plant, they are sometimes, though rarely, a little more fertile; if fertilized with pollen from another individual or variety of the same species, they are fully fertile; but if with pollen from a distinct species, they are sterile in all possible degrees, until utter sterility is reached. We thus have a long series with absolute sterility at the two ends; at one end due to the sexual elements not having been sufficiently differentiated, and at the other end to their having been differentiated in too great a degree, or in some peculiar manner."

The difficulties in the way of successful results through hybridization are, therefore, these: the difficulty of effecting the cross; infertility, instability, variability, and often weakness and monstrosity of the hybrids; and the absolute impossibility of predicting results. The advantage to be derived from a successful hybridization is the securing of a new variety which shall combine in some measure the most desirable features of both parents; and this advantage is often of so great moment that it is worth while to make repeated efforts and to overlook numerous failures. From these theoretical considerations it is apparent that hybridization is essentially an empirical subject, and the results are such as fall under the common denomination of chance. And, as it does not rest upon any legitimate function in nature, we can understand that it will always be difficult to codify laws upon it.

Among the various characters of hybrid offspring, I presume that the most prejudicial one is their instability, their tendency still to vary into new forms or to return to one or the other parent in succeeding generations. It is difficult to fix any particular form which we may secure in the first generation of hybrids. At the outset, we notice that this discouraging feature is manifested chiefly through the fact of seed-reproduction, and we thereby come upon what is perhaps the most important practical consideration in hybridization, — the fact that the great majority of the best hybrids in cultivation are increased by bud-propagation, as cuttings, layers, suckers, buds, or grafts. In fact, I recall very few instances in this country of good undoubted hybrids which are propagated with practical certainty by means of seeds. You will recall that the genera in which hybrids are most common are those in which bud-propagation is the rule; as begonia, pelargonium, orchids, gladiolus, rhododendron, roses, cannas, and the fruits. This simply means that it is difficult to fix hybrids so that they will come "true to seed," and makes apparent the fact that if we desire hybrids we must expect to propagate them by means of buds.

This is a point which appears to have been overlooked by those who contend that hybridization must necessarily swamp all results of natural selection; for, as comparatively few plants propagate habitually by means of buds, whatever hybrids might have appeared would have been speedily lost, and all the more, also, because, by the terms of their reasoning, the hybrids would cross with other and dissimilar forms, and therefore lose their identity as intermediates. Or, starting with the assumption that hybrids are intermediates, and would therefore obliterate specific types, we must conclude that they should have some marked degree of stability if they are to swamp or obliterate the characters of species; but, as all hybrids tend to break up when propagated by seeds, it must follow that bud-propagation would become more and more common, and this is associated in nature with decreased seed-production. Now, seed-production is the legitimate function of flowers; and we must concede that, as seed-production decreased, floriferousness must have decreased; and that, therefore, pronounced intercrossing would have obliterated the very organs upon which it depends, or have destroyed itself!

But I may be met by the objection that there is no inherent reason why hybrids should not become stable through seed-production by in-breeding, and I might be cited to the opinion of Darwin and others that in-breeding tends to fix any variety, whether it originates by crossing or other means. And it is a fact that in-breeding tends to fix varieties within certain limits, but those limits are often overpassed in the case of very pronounced crosses, whether cross-breeds or true hybrids. And if it is true, as all observation and experiments show, that sexual or reproductive powers of crosses are weakened as the cross becomes more violent, we should expect less and less possibility of successful in-breeding; for in-breeding without disastrous results is possible only with comparatively strong reproductive powers. As a matter of fact, it is found in practice that it is exceedingly difficult to fix pronounced hybrids by means of in-breeding. It sometimes happens, too, that the hybrid individual which we wish to perpetuate may be infertile with itself, as I have often found in the case of squashes. It is often advised that we cross the hybrid individual which we wish to fix with another like individual, or with one of its parents. These results are often successful, but oftener they are not. In the first place, it often happens that the hybrid individuals may be so diverse that no two of them are alike; this has been my experience in many crosses. And, again, crossing with a parent may draw the hybrid back again to the parental form. So long ago as last century Kölreuter proved this fact upon nicotiana and dianthus. A hybrid between Nicotiana rustica and N. paniculata was crossed with N. paniculata until it was indistinguishable from it; and it was then crossed with N. rustica until it became indistinguishable from that parent. Yet there is no other way of fixing a hybrid to be propagated by seeds than by in-breeding, and by constant attention to selection. Fortunately, it occasionally happens that a hybrid is stable, and therefore needs no fixing.

In this connection I may cite some of my own experience in crossing egg-plants and squashes; for, although the products were not true hybrids in the strict interpretation of the word, many of them were hybrids to all intents and purposes, because made between very unlike varieties, and they will serve to illustrate the difficulties of which I speak. Offspring of egg-plant crosses were grown in 1890, and upon some of the most promising plants some flowers were self-pollinated. But these self-pollinated seeds gave just as variable offspring in 1891, as those selected almost at random from the patch; and, what was worse, none of them reproduced the parent, or "came true to seed," and all further motive for in-breeding was gone. My labor, therefore, amounted to nothing more than my own edification. My experience in crossing pumpkins and squashes has now extended through many years; and, although I have obtained about one thousand types not named or described, I have not yet succeeded in fixing one. The difficulty here is an aggravated one, however. The species are so exceedingly variable that all the hybrid individuals may be unlike, so that there can be no crossing between identical stocks; and, if in-breeding is attempted, it may be found that the flowers will not in-breed. And the refusal to in-breed is all the more strange because the sexes are separated in different flowers upon the same plant. In other words, in my experience, it is very difficult to get good seeds from squashes which are fertilized by a flower upon the same vine. The squashes may grow normally to full maturity, but be entirely hollow, or contain only empty seeds. In some instances the seeds may appear to be good, but may refuse to grow under the best conditions. Finally, a small number of flowers may give good seeds. I have many times observed this refusal of squashes (Cucurbita Pepo) to in-breed. It was first brought to my attention through efforts to fix certain types into varieties. The figures of one season's tests will sufficiently indicate the character of the problem. In 1890, one hundred and eighty-five squash flowers were carefully pollinated with staminate flowers taken from the same vine which bore the pistillate flowers. Only twenty-two of these produced fruit, and of these only seven, or less than one-third, bore good seeds, and in some of these the seeds were few. Now, these twenty-two fruits represented as many different varieties, so that the inability to set fruit with pollen from the same vine is not a peculiarity of a particular variety. The records of the seeds of the seven fruits in 1891 are as follows: —

Fruit No. 1. — Four vines were obtained, with four different types, two of them being white, one yellow, and one black.

Fruit No. 2. — Twenty-three vines. Fifteen types very unlike, twelve being white and three yellow.

Fruit No. 3. — Two vines. One type of fruit which was almost like one of the original parents.

Fruit No. 4. — Thirty-two vines. Six types, differing chiefly in size and shape.

Fruit No. 5. — Twenty vines. Nineteen types, of which ten were white, eight orange, one striped, and all very unlike.

Fruit No. 6. — Thirteen vines. Eleven types, — eight yellow, two black, one white.

Fruit No. 7. — One vine.

These offspring were just as variable as those from flowers not in-bred, and no more likely, apparently, to reproduce the parent. These tests leave me without any method of fixing a pronounced cross of squashes, and lead me to think that the legitimate process of origination of new kinds here, as, indeed, if not in general, is a more gradual process of selection, coupled, perhaps, with minor crossing.

I will relate a definite attempt towards the fixation of a squash which I had obtained from crossing. The history of it runs back to 1887, when a cross was effected between a summer yellow crookneck and a white bush scallop squash. In 1889 there appeared a squash of great excellence, combining the merits of summer and winter squashes with very attractive form, size, and color, and a good habit of plant. I showed the fruit to one of the most expert seedsmen of the country, and he pronounced it one of the most promising types which he had ever seen; and, as he informed me that he had fixed squashes by breeding in and in, I was all the more anxious to carry out my own convictions in the same direction. It is needless to say that I was very happy over what I regarded as a great triumph. Of course I must have a large number of plants of my new variety, that I might select the best, both for in-breeding and for crossing similar types. So I selected the very finest squash, having placed it where I could admire it for some days, and saved every seed of it. These seeds were planted upon the most conspicuous knoll in my garden in 1890. It was soon evident that something was wrong. I seemed to have everything except my squash. One plant, however, bore fruits almost like the parent, and upon this I began my attempts towards in-breeding. But flower after flower failed, and I soon saw that the plant was infertile with itself. Careful search revealed two or three other plants very like this one, and I then proceeded to make crosses upon it. I was equally confident that this method would succeed. When I harvested my squashes in the fall and took account of stock, I found that the seeds of my one squash had given just as many different types as there were plants, and I actually counted one hundred and ten kinds distinct enough to be named and recognized. Still confident, in 1891 I planted the seeds of my few crosses, and as the summer days grew long and the crickets chirped in the meadows, I watched the expanding squash blossoms and wondered what they would bring forth. But they brought only disappointment. Not one seed produced a squash like the parent. My squash had taken an unscientific leave of absence, and I do not know its whereabouts. And when the frost came and killed every ambitious blossom, my hope went out and has not yet returned!

Let us now recall how many undoubted hybrids there are, named and known, among our fruits and vegetables. In grapes there are the most. There are Rogers' hybrids, like the Agawam, Lindley, Wilder, Salem, and Barry; and there is some reason for supposing that the Delaware, Catawba, and other varieties are of hybrid origin. And many hybrids have come to notice lately through the work of Munson and others. But it must be remembered that grapes are naturally exceedingly variable, and the specific limits are not well known, and that hybridization among them lacks much of that definiteness which ordinarily attaches to the subject. In pears there is the Kieffer class. In apples, peaches, plums, cherries, gooseberries, and currants, there are no important commercial hybrids. In blackberries there is the blackberry-dewberry class, represented by the Wilson Early and others. Some of the raspberries, like the Philadelphia and Shaffer, are hybrids between the red and black species. Hybrids have been produced between the raspberry and blackberry by two or three persons, but they possess no promise of economic results. Among all the list of garden vegetables (plants which are propagated by seeds) I do not know of a single important hybrid; and the same is true of wheat, — unless the Carman wheat-rye varieties become prominent, — oats, the grasses, and other farm crops. But among ornamental plants there are many; and it is a significant fact that the most numerous, most marked, and most successful hybrids occur in the plants most carefully cultivated and protected, those, in other words, which are farthest removed from all untoward circumstances and an independent position. This is nowhere so well illustrated as in the case of cultivated orchids, in which hybridization has played no end of freaks, and in which, also, every individual plant is nursed and coddled.[1] With such plants the struggle for existence is reduced to its lowest terms; for it must be borne in mind that, even in the garden, plants must fight severely for a chance to live, and even then only the very best can persist, or are even allowed to try.

I am sure that this list of hybrids is much more meagre than most catalogues and trade-lists would have us believe, but I am sure that it is approximately near the truth. It is, of course, equivalent to saying that most of the so-called hybrid fruits and vegetables are myths. There is everywhere a misconception of what a hybrid is, and how it comes to exist; and yet, perhaps because of this indefinite knowledge, there is a wide-spread feeling that a hybrid is necessarily good, while the presumption is directly the opposite. The identity of a hybrid in the popular mind rests entirely upon some superficial character, and proceeds upon the assumption that it is necessarily intermediate between the parents. Hence we find one of our popular authors asserting that, because the kohlrabi bears its thickened portion midway of its stem, it is evidently a hybrid between the cabbage and turnip, which bear respectively the thickened parts

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[1] Consult E. Bohnhof, "Dictionnaire des Orchidées Hybrides," Paris, 1895.

at the opposite extremities of the stem! And then there are those who confound the word hybrid with *high-bred*, and who build attractive castles upon the unconscious error. And thus is confusion confounded!

But, before leaving this subject of hybridization, I must speak of the old yet common notion that there is some peculiar influence exerted by each sex in the parentage of hybrids; for I shall thereby not only call your attention to what I believe to be an error, but shall also find the opportunity to still further illustrate the entanglements of hybridization. It was held by certain early observers, of whom the great Linnæus was one, that the female parent determines the constitution of the hybrid, while the male parent gives the external attributes, as form, size, and color. The accumulated experience of nearly a century and a half appears to contradict this proposition, and Focke, who has recently gone over the whole ground, positively declares that it is untrue. There are instances, to be sure, in which this old idea is affirmed, but there are others in which it is contradicted. The truth appears to be this, — that the parent of greater strength or virility makes the stronger impression upon the hybrids, whether it is the staminate or pistillate parent; and it appears to be equally true that it is usually impossible to determine beforehand which parent is the stronger. It is certain that strength does not lie in size, neither in the high development of any character. It appears to be more particularly associated with what we call fixity or stability of character, or the tendency towards invariability.

This has been well illustrated in my own experiments with squashes, gourds, and pumpkins. The common little pear-shaped gourd will impress itself more strongly upon crosses than any of the edible squashes and pumpkins with which it will effect a cross, whether it is used as male or female parent. Even the imposing and ubiquitous great field pumpkin, which every New Englander associates with pies, is overpowered by the little gourd. Seeds from a large and sleek pumpkin which had been fertilized by gourd pollen, produced gourds and small hard-shelled globular fruits which were entirely inedible. A more interesting experiment was made between the handsome green-striped Bergen fall squash and the little pear gourd. Several flowers of the gourd were pollinated by the Bergen in 1889. The fruits raised from these seeds in 1890 were remarkably gourd-like. Some of these crosses were pollinated again in 1890 by the Bergen, and the seeds were sown in 1891. Here, then, were crosses into which the gourd had gone once and the Bergen twice, and both the parents are to all appearances equally fixed, the difference in strength, if any, attaching rather to the Bergen.

Now, the crop of 1891 still carried pronounced characters of the gourd. Even in the fruits which most resembled the Bergen, the shells were almost flinty hard, and the flesh, even when thick and tender, was bitter. Some of the fruits looked so much like the Bergen that I was led to think that the gourd had largely disappeared. The very hard but thin paper-like shell which the gourd had laid over the thick yellow flesh of the Bergen, I thought might serve a useful purpose, and make the squash a better keeper. And I found that it was a great protection, for the squash could stand any amount of rough handling, and was even not injured by ten degrees of frost. All this was an acquisition, and, as the squash was handsome and exceedingly productive, nothing more seemed to be desired. But it still remained to have a squash for dinner. The cook complained of the hard shell, but, once inside, the flesh was thick and attractive, and it cooked nicely. But the flavor! Dregs of quinine, gall, and boneset! The gourd was still there!

VI. Uncertainties of Pollination.

We have now seen that uncertainty follows hybridization, and, in closing, I will say that uncertainty also attaches to the mere act of pollination. Between some species which are closely allied and which have large and strong flowers, four-fifths of the attempts towards cross-pollination may be successful; but such a large proportion of successes is not common, and it may be infrequent even in pollinations between plants of the same species or variety. Some of the failure is due in many cases to unskilful operation, but even the most expert operators fail as often as they succeed in promiscuous pollinating. There is good reason to believe, as Darwin has shown, that the failure may be due to some selective power of individual plants, by which they refuse pollen which is, in many instances, acceptable to other plants even of the same variety or stock. The lesson to be drawn from these facts is that operations should be as many as possible, and that discouragement should not come from failure. In order to illustrate the varying fortunes of the pollinator, I will transcribe some notes from my field-book.

Two hundred and thirty-four pollinations of gourds, pumpkins, and squashes, mostly between varieties of one species (Cucurbita Pepo), and including some individual pollinations, gave one hundred and seventeen failures and one hundred and seventeen successes. These crosses were made in varying weather, from July 28 to August 30. In some periods nearly all the operations would succeed, and at other times most of them would fail. I have always regarded these experiments as among my most successful ones, and yet but half of the pollinations "took." But one must not understand that I actually secured seeds from even all these one hundred and seventeen fruits, for some of them turned out to be seedless, and some were destroyed by insects before they were ripe, or they were lost by accidental means. A few more than half of the successful pollinations — if by success we mean the formation and growth of fruit — really secured us seeds, or about one-fourth of the whole number of efforts.

Twenty pollinations were made between potato flowers, and they all failed; also, seven pollinations of red peppers, four of husk-tomato, two of Nicotiana affinis upon petunia and two of the reciprocal cross, twelve of radish, one of Mirabilis Jalapa upon M. longiflora and two of the reciprocal cross, three Convolvulus major upon C. minor and one of the reciprocal, one muskmelon by squash, two muskmelons by watermelon, and one muskmelon by cucumber.

This is but one record. Let me give another: —

Cucumber, ninety-five efforts: fifty-two successes, forty-three failures. Tomato, forty-three efforts: nineteen successes, twenty-four failures. Egg-plant, seven efforts: one success, six failures. Pepper, fifteen efforts: one success, fourteen failures. Husk-tomato, forty-five efforts: forty-five failures. Pepino, twelve efforts: twelve failures. Petunia by Nicotiana affinis, eleven efforts: eleven failures. Nicotiana affinis by petunia, six efforts: six failures. General Grant tobacco by Nicotiana affinis, eleven efforts: eight successes, three failures. Nicotiana affinis by General Grant tobacco, fifteen efforts: fifteen failures. General Grant tobacco by General Grant tobacco, one effort: one success. Nicotiana affinis by Nicotiana affinis, three efforts: two successes, one failure. Tuberous begonia, five efforts: five successes.

Total, three hundred and twelve efforts: eighty-nine successes, two hundred and twenty-three failures.

CONCLUSION.

And now, the sum of it all is this: encourage in every way crosses within the limits of the variety and in connection with change of stock, expecting increase in vigor and productiveness; hybridize if you wish to experiment, but do it carefully, systematically, thoroughly, and do not expect too much. Extend Darwin's famous proposition to read: Nature abhors both perpetual self-fertilization and hybridization.

LECTURE III.

HOW DOMESTIC VARIETIES ORIGINATE.

"THE key is man's power of accumulative selection: nature gives successive variations; man adds them up in certain directions useful to him." This, in Darwin's phrase, is the essence of the cultivator's skill in ameliorating the vegetable kingdom. So far as man is concerned, the origin of the initial variation is largely chance, but this start or variation once given, he has the power, in most cases, to perpetuate it and to modify its characters. There are, then, two very different factors or problems in the origination of garden varieties, — the production of the first departure or variation, and the subsequent breeding of it. Persons who give little thought to the subject, look upon variation as the end of their endeavors, thinking that a form comes into being with all its characters well marked and fixed. In reality, however, variation is but the beginning; selection is the end.

I. INDETERMINATE VARIETIES.

There are two general classes of garden varieties as respects the method of their origin, —

those which come into existence somewhat suddenly and which require little else of the husbandman than the multiplication of them, and those which are the result of a slow evolution or direct breeding. The former are indeterminate or uncertain, and the latter are determinate or definite. The greater part of those in the first class are plants which are multiplied or divided by bud-propagation. They comprise nearly all our fruits, the woody ornamental plants, and such herbaceous genera as begonia, canna, gladiolus, lily, dahlia, carnation, chrysanthemum, and the like, — in fact, all those multiplied by grafting, cuttings, bulbs, or other asexual parts. The original plant may be either a seedling or a bud-sport. The gardener, who is always on the lookout for novelties, discovers its good qualities and propagates it.

Varieties which are habitually multiplied by buds, as in those plants which I have mentioned in the last paragraph, vary widely when grown from seeds, so that every seedling may be markedly distinct. As soon, however, as varieties are widely and exclusively propagated by seeds, they develop a capability of carrying the greater part of the individual differences down to the offspring. That is, seedlings from bud-multiplied plants do not "come true," as a rule, whilst those from seed-propagated plants do "come true." The reason of this difference will become apparent upon a moment's reflection. In the seed-propagated plants, like the kitchen-garden vegetables and the annual flowers, we select the seeds and thereby eliminate all those variations which would have arisen had the discarded seeds been sown. In other words, we are constantly fixing the tendency to "come true," for this feature of plants is as much a variation as form or color or any other attribute is. Suppose, for instance, that a certain variation were to receive two opposite treatments, the seeds from one-half of the progeny being carefully selected year by year, and all those from untypical plants discarded, whilst in the other half all the seeds from all the plants, whether good or bad, are saved and sown. In the one case, it will be seen, we are fixing the tendency to "come true," for this is all that constitutes a horticultural variety,— a brood which is very much like all its parents. In the other case, we are constantly eliminating the tendency to "come true" by allowing every modifying agency full sway. So the very act of taking seeds only from plants which have "come true," tends to still more strongly fix the hereditary force within narrow limits. Working against this restrictive force, however, are all the agencies of environment, so that, fortunately, now and then a seed gives a "rogue," or a plant widely unlike its parent, and this may be the start for a new variety.

With bud-multiplied varieties, however, the case is very different. Here every seed may be sown, as in the illustrative case above, because the seedlings are not wanted for themselves, but simply as stocks upon which to bud or graft the desired varieties. So there is no seed selection in the ordinary propagation of apples, pears, peaches, and the other orchard fruits. The seeds are taken indiscriminately from pomace or the refuse of canning and evaporating factories. But every annual garden vegetable is always grown from seeds more or less carefully saved from plants which possess some desired attribute. There is no reason why the tree fruits should not reproduce themselves from seeds just as closely as the annual herbs do, if they were to be as carefully propagated by selected seeds through a long course of generations. There is excellent proof of this in the well-marked races or families of Russian apples. In that country, grafting has been little employed, and consequently it has been necessary to select seeds only from acceptable trees in order that the offspring might be more acceptable. So the Russian apples have come to run in groups or families, each family bearing the mark of some strong ancestor. Most of the seedlings of the Duchess of Oldenburg are recognizable because of their likeness to the parent. We may thus trace an incipient tendency in our own fruits towards racial characters. The Fameuse type of apples, for example, tends to perpetuate itself; and a similar tendency is very well marked in the Damson and Green Gage plums, the Orange quince, Concord grape, and Hill's Chili and Crawford peaches. But inasmuch as bud-multiplication is so essential in nursery practice, we can hardly hope for the time when our trees and shrubs, or even our perennial herbs, will "come true" with much certainty. In them, therefore, we get new varieties by simply sowing the seeds; but in seed-propagated varieties we must depend either upon chance variations or else we must resort to definite plant-breeding.

II. Plant-breeding.

The breeding of domestic animals is attended, for the most part, with such definite and often precise results that there has come to be a general desire to extend the same principles to plants. It is not unusual to hear well-informed people say that it is possible to breed plants with as much certainty and exactness as it is to breed animals. The fact is, however, that such exactness will never be possible, because plants are very unlike animals in organization, and because, also, the objects sought in the two cases are characteristically unlike. Plants, as we have seen, are made up of a colony of potential individuals, and to breed between two plants by crossing means that we must choose the sex-parents from amongst as many individuals as there are flowers or branches on the two plants, whilst in animals we choose two definite personal parents. And these personal parents are either male or female, and the union is essential to the production of offspring, whilst in plants each parent — that is, each flower — is generally both male and female, and the union of two is not essential to the production of offspring, for the plant is capable of multiplying itself by buds. The element of chance, therefore, is one hundred, or more, to one in crossing plants as compared with crossing animals. Then, again, the plant-parents are modified profoundly by every environmental condition of soil and temperature and sunshine, or other external condition, since they possess no bodily temperature, no choice of conditions, and no volition to enable them to overcome the circumstances in which they are placed. Animals, on the contrary, have all these elements of personality, and the breeder is also able to control the conditions of their lives to a nicety. In view of all these facts, it is not strange that animals can be bred by crossing with more confidence than plants can. But there is another and even more important difference between the breeding of animals and the breeding of plants. In animals, our sole object is to secure simply one animal or one brood of offspring. In plants, our object is, in general, to secure a race or generations of offspring, which may be disseminated freely over the earth. In the bovine race, for example, our object in breeding is to produce one cow with given characters; in turnips, our object is to produce a new variety, the seed of which will reproduce the variety, whether sown in Pennsylvania or Ceylon. It is apparent, therefore, that any comparisons drawn between the breeding of animals and plants are likely to be fallacious.

Is there, then, any such thing as plant-breeding, any possibility that the operator can proceed with some confidence that he may obtain the ideal which he has in mind? Yes, to a certain extent.

It is apparent that the very first effort on the part of the plant-breeder must be to secure individual differences; for so long as the plants which he handles are very closely alike, so long there will be little hope of obtaining new varieties. He must, therefore, cause his plants to vary. In plants which are comparatively unvariable, it is frequently impossible to produce variations in the desired direction at once, but it is more important to "break" the type,—that is, to make it depart markedly from its normal behavior in any or many directions (page 19). If the type once begins to vary, to break up into different forms, the operator may be sure that it will soon become plastic enough to allow of modification in the manner which he desires. But whilst it is important or even necessary to break a well-marked type into many forms, it would no doubt be unwise to encourage this tendency after it once appears, lest the plant acquire a too strong habit of scattering. This initial variation is induced by changing the conditions in which the plant has habitually grown, as a change of seed, change of soil, tillage, varying the food supply, crossing and the like.

As a matter of fact, however, nearly all plants which have been long cultivated are already sufficiently variable to afford a starting-point for breeding. The operator should have a vivid mental picture of the variety which he designs to obtain ; then he should select that plant in his plantation which is the nearest his ideal, and sow the seeds of it. From the seedlings he should again select the individuals which most nearly approach his type, and so on, generation after generation, until the desired object is attained. It is important, if he is to make rapid progress, that he keep the same ideal in mind year by year, otherwise there will be vacillation and the progress of one year may be undone by a counter movement the following year. In this way, it will be found that almost any character of a plant may be either intensified or lessened. This is man's nearest approach to the Creator in his dominion over the physical forms of life, and it is great and potent in proportion as it sets for itself correct ideals in the beginning and adheres to them until the end.

When beginning this selection or breeding for an ideal, it is important that impossible or contradictory results should be avoided. Some of the cautions and suggestions which need to be considered are these: —

1. *Avoid striving after features which are antagonistic or foreign to the species or genus with which you are working.* Every group of plants has become endowed with certain characters or lines of development, and the cultivator will secure quicker and surer results if he works along the same lines, rather than to attempt to thwart them. Nature gives the hint: let men follow it out, rather than to endeavor to create new types of characters. Let us take some of the solanaceous plants as examples. There are certain types of the genus solanum which have a natural habit of tuber-bearing, as the potato. Such species should be bred for tubers and not for fruits. There are other solanums, however, like the egg-plants and the pepinoes, which naturally vary or develop in

the direction of fruit-bearing, and these should be bred for fruits and not for tubers ; and the same should be true in the related genera of tomatoes, red peppers, and physalis. Those ambitious persons who are always looking for a tuber-bearing tomato, therefore, might better concentrate their energies on the potato, for the tomato is not developing in that direction ; and even if the tomato could be made to produce tubers, it would thereby lessen its fruit production, for plants cannot maintain two diverse and profitable crops at the same time. It is more reasonable, and certainly more practicable, to grow potatoes on potato plants and tomatoes on tomato plants.

2. *The quickest and most marked results are to be expected in those groups or species which are normally the most variable.* There are a greater number of variations or starting-points in such species ; but it also follows that the forms are less stable the more the species is variable. Yet the variations, being very plastic, yield themselves readily to the wishes of the operator. Carrière puts the thought in this form : "The stability of forms, in any group of plants, is, in general, in inverse ratio to the number of the species which it contains, and also to the degree of its domestication."

The most variable types are the most dominant ones over the earth ; that is, they occur in greater numbers and under more diverse conditions than the comparatively invariable types do. The compositæ, or sunflower-like plants, comprise a ninth or tenth of the total species of flowering plants, and the larger part of the subordinate types or genera contain many forms or species. Aster, goldenrod, the hawkweeds, thistles, and other groups, are representative of the cosmopolitan or variable types of composites. Whenever, for any reason, any type begins to decline in variability, it also begins to perish; it is then tending towards extinction. Monotypic genera — those which contain but a single species — are generally of local or disconnected distribution, and are, for the most part, vanishing remnants of a once dominant or important type. As a rule, most of our widely variable and staple cultivated species are members of large, or at least polytypic genera. Such, for example, are the apples and pears, peaches and plums, oranges and lemons, roses, bananas, chrysanthemums, pinks, cucurbits, beans, potato, grapes, barley, rice, cotton. A marked exception to this statement is maize, which is immensely variable and is generally held to have come from a single species; but the genesis of maize is unknown, and it is possible, though scarcely probable, that more than one species is concerned in it. Wheat is also a partial exception, although the original specific type is not understood; and the latest monographers admit three or four other species to the genus, aside from wheat. There are other exceptions, but they are mostly unimportant, and, in the main, it may be said that the dominant domestic types of plants represent markedly polytypic genera.

3. *Breed for one thing at a time.* The person who strives at the same time for increase or modification in prolificacy and flavor will be likely to fail in both. He should work for one object alone, simply giving sufficient attention to subsidiary objects to keep them up to normal standard. This is really equivalent to saying that there can be no such thing as the perfect all-around variety which so many people covet. Varieties must be adapted to specific uses, — one for shipping, one for canning, one for dessert, one for keeping qualities, and the like. The more good varieties there are of any species, the more widely and successfully that species can be cultivated.

4. *Do not desire contradictory attributes in any variety.* A variety, for example, which bears the maximum number of fruits or flowers cannot be expected to greatly increase the size of those organs without loss in numbers. This is well shown in the tomato. The original tomato produced from six to ten fruits in a cluster, but as the fruits increased in size the numbers in each cluster fell to two or three. That is, increase in size proceeded somewhat at the expense of numer-

ical productivity; yet the total weight of fruit per plant has greatly increased. The same is true of apples and pears; for whilst these trees bear flowers in clusters, they generally bear their fruits singly. Originally, every flower normally set fruit. The reason why blackberries, currants, and grapes do not increase more markedly in size, is probably because the size of cluster has been given greater attention than the size of berry. Plants which now bear a full crop of tubers cannot be expected to increase greatly in fruit-bearing, as I have already explained under Rule 1. This fact is illustrated in the potato, in which, as tuber production has increased, seed production has decreased, so that potato growers now complain that potatoes do not produce bolls as freely as they did years ago.

5. *When selecting seeds, remember that the character of the whole plant is more important than the character of any one branch or part of the plant; and the more uniform the plant in all its parts, the greater is the likelihood that it will transmit its characters.* If one is striving for larger flowers, for instance, he will secure better results if he choose seeds from plants which bear large flowers throughout, than he will if he choose them from some one large-flowering branch on a plant which bears indifferent flowers on the remaining branches, even though this given branch produce much larger

flowers than those borne on the large-flowered plant. Small potatoes from productive hills give a better product than large potatoes from unproductive hills. The practice of selecting large ears from a bin of corn, or large melons from the grocer's wagon, is much less efficient in producing large products the following season than the practice of going into the fields and selecting the most uniformly large-fruited parents would be. A very poor plant may occasionally produce one or two very superior fruits, but the seeds are more likely to perpetuate the characters of the plant than of the fruits.

The following experiences detailed by Henri L. de Vilmorin illustrate my proposition admirably: "I tried an experiment with seeds of Chrysanthemum carinatum gathered on double, single, and semi-double heads, all growing on one plant, and found no difference whatever in the proportion of single and double-flowered plants. In striped verbenas, an unequal distribution of the color is often noticed; some heads are pure white, some of a self color, and most are marked with colored stripes on white ground. I had seeds taken severally from all and tested alongside one another. The result was the same. All the seeds from one plant, whatever the color of the flower that bore them, gave the same proportion of plain and variegated flowers."

The second part of my proposition is equally as important as the first,—the fact that a plant which is uniform in all its branches or parts is more likely to transmit its general features than one which varies within itself. It is well known that bean plants often produce beans with various styles of markings on the same plant or even in the same pod, yet these variations rarely ever perpetuate themselves. The same remark may be applied to variations in peas. These illustrations only add emphasis to the fact that intending plant-breeders should give greater heed than they usually do to the entire plant, rather than confine their attention to the particular part or organ which they desire to improve.

At first thought, it may look as if these facts are directly opposed to the proposition which I emphasized in my first lecture, that every branch of a plant is a potential autonomy, but it is really a confirmation of it. The variation itself shows that the branch is measurably independent, but it is not until the conditions or causes of the variation are powerful enough to affect the entire plant that they are sufficiently impressed upon the organization of the plant to make their effects hereditary.

There is an apparent exception to the law that the character of the entire plant is more important than any one organ or part of it, in the case of the seeds themselves. That is, better results usually follow the sowing of large and heavy seeds than of small or unselected seeds from the same plant. This, however, does not affect the main proposition, for the seed is in a measure independent of the plant-body, and is not so directly influenced by environment as the other organs are. And, again, the seed receives a part of its elements from a second or male parent. The good results which follow the use of large seeds are, chiefly, greater uniformity of crop, increased vigor, often a gain in earliness and sometimes in bulk, and generally a greater capacity for the production of seeds. These results are probably associated less with any innate hereditable tendencies than with the mere vegetative strength and uniformness of the large seeds. The large seeds usually germinate more quickly than the small ones, provided both are equally mature, and they push the plantlet on more vigorously. This initial gain, coming at the most critical time in the life of the new individual, is no doubt responsible for very much of the result which follows. The uniformity of crop is the most important advantage which comes of the use of large seeds, and this is obviously the result of the elimination of all seeds of varying degrees of maturity, of incomplete growth and formation, and of low vitality.

Another important consideration touching the selection of seeds is the fact that very immature seeds give a feeble but precocious progeny. This has long been observed by gardeners, but Sturtevant, Arthur, and Goff have recently made a critical examination of the subject. "It is not the slightly unripe seeds that give a noticeable increase in earliness," according to Arthur, "but very unripe seeds, gathered from fruit [tomatoes] scarcely of full size and still very green. Such seeds do not weigh more than two-thirds as much as those fully ripe. They germinate readily, but the plantlets lack constitutional vigor and are more easily affected by retarding or harmful influences. If they can be brought through the early period of growth and become well established, and the foliage or fruit is not attacked by rots or blights, the grower will usually be rewarded by an earlier and more abundant crop of slightly smaller and less firm fruit. These characters will be more strongly emphasized in subsequent years by continuous seed propagation." Goff remarks that the increase in earliness in tomatoes, following the use of markedly immature seeds, "is accompanied by a marked decrease in the vigor of the plant, and in the size, firmness, and keeping quality of the fruit." These results are probably closely associated with the chemical constitution and content of the immature seeds.

The organic compounds have probably not yet reached a state of stability, and they therefore respond quickly to external stimuli when placed in conditions suitable to germination; and there is little food for the nourishment of the plantlet. The consequent weakness of the plantlet results in a loss of vegetative vigor, which is earliness (see Rule 11).

Still another feature connected with the choice of seeds is the fact that in some plants, as in some Ipomœas, for example, the color of the seed is more or less intimately associated with the color of the flower which produced them and also with the color of the flowers which they will produce.

6. *Plants which have any desired characteristics in common may differ widely in their ability to transmit these characters.* It is generally impossible for the cultivator to determine, from the appearance of any given number of similar plants, which of them will give progeny the most unvariable and the most like its parent; but it may be said that those individuals which grow in the most usual or normal environments are most likely to perpetuate themselves. A very unusual condition, as of soil, moisture, or exposure, is not easily imitated when providing for the succeeding generation, and a return to normal conditions of environment may be expected to be followed by a more or less complete return to normal attributes on the

part of the plant. If the same variation, therefore, were to occur in plants growing under widely different conditions, the operator who wishes to preserve the new form should take particular care to select his seeds from those individuals which seem to have been least influenced by the immediate conditions in which they have grown.

Again, if the same variation appears both in uncrossed and crossed plants, the best results should be expected in selecting seeds from the former. We have already seen, in the second lecture, how it is that crosses are unstable, and how the instability is apt to be the greater the more violent the cross. "Cross-breeding greatly increases the chance of wide variation," writes Henri L. de Vilmorin, "but it makes the task of fixation more difficult."

It is very important, therefore, when selecting seeds from plants which seem to give promise of a new variety, to sow the seeds of each plant separately, and then make the subsequent selections from the most stable generation; and it is equally important that the operator should not trust to a single plant as a starting-point, whenever he has several promising plants from which to choose.

7. *The less marked the departure from the genius of the normal type, the greater, in general, is the likelihood that it will be perpetuated.* That

is, widely aberrant forms are generally unstable. This is admirably illustrated in crosses. The seed-progeny of crosses between closely related varieties, or between different plants of the same variety, is more uniform and generally more easy of improvement by selection than the progeny of hybrids. In uncrossed plants, the general tendency is to resemble their parents, and the greater the number of like ancestors, the greater is the tendency to "come true." There is thought to be a tendency, though necessarily a weak one, to return to some particular ancestor, or to "date back." This is known as atavism. The so-called atavistic forms are likely to be unstable, to break up into numerous forms, or to return more or less completely to the type of the main line of the ancestry. The following statements touching some of the relations of atavism to the amelioration of plants, are the results of an excellent study of heredity in lupines by Louis Levêque de Vilmorin: —

"1. The tendency to resemble its parents is generally the strongest tendency in any plant;

"2. But it is notably impaired as it comes into conflict with the tendency to resemble the general line of its ancestry.

"3. This latter tendency, or atavism, is constant, though not strong, and scarcely becomes impaired by the intervention of a series of generations in which no reversion has taken place.

"4. The tendency to resemble a near progenitor (only two or three generations removed), on the other hand, is very soon obliterated if the given progenitor is different from the bulk of its ancestors."

8. *The crossing of plants should be looked upon as a means or starting-point, not as an end.* We cross two flowers and sow the seeds. The resulting seedlings may be unlike either parent. Here, then, is variation. The operator should select that plant which most nearly satisfies his ideal, and then, by selection from its progeny and the progeny of succeeding generations, gradually obtain the plant which he desires. It is only in plants which are propagated by asexual parts—as grafts, cuttings, layers, bulbs, and the like—that hybrids or crosses are commonly immediately valuable; for in these plants we really cut up and multiply the one individual plant which pleases us in the first batch of seedlings, rather than to take the offspring or seedlings of it. Thus, if any particular plant in a lot of seedlings of crosses of cannas, or plums, or hops, or strawberries, or potatoes, is valuable, we multiply that one individual. There is no occasion for fixing the variety. But any satisfactory plant in a lot of seedlings of crosses of pumpkins, or wheat, or beans, must be made the parent of a new variety by sowing the seeds of it and then by selecting for seed-

parents, year by year, those plants which are best. "The unsettled forms arising from crosses," Focke writes, "are the plastic material out of which gardeners form their varieties."

But even in the fruits, and other bud-propagated plants, crossing may often be used to as good advantage for the purpose of originating variation as it can in peas or buckwheat. It only requires a longer time to fix and select variations because the plants mature so slowly. Ordinarily, if the operator does not find satisfactory plants amongst the seedlings of any cross of fruit trees, he roots up the whole batch as profitless. But if he were to allow the best plants to stand and were to sow seeds from them, the second generation might produce something more to his liking. But it is generally quicker to make another cross and to try the experiment over again, than to wait for unpromising seedlings to bear. This repeated repetition of the experiment, however, — continual crossing and sowing and uprooting, — is gambling. Throwing dice to see what will turn up is a comparable proceeding. The sowing of uncrossed seed is little better. Peter M. Gideon sowed over a bushel of apple seed, and one seed produced the Wealthy apple.[1]

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[1] The facts in the origination of the Wealthy apple, as related to me by Mr. Gideon, are these: he first planted a bushel of apple seeds, and then each year, for nine years, he planted

D. B. Wier raised a million seedlings of soft maple, and one plant of the lot had finely divided leaves, and is now Wier's Cutleaved maple. Teas' Weeping mulberry, which is now so deservedly popular, was, as Mr. Teas tells me, "merely an accidental seedling." So this explains why the production of new varieties of fruits is always chance, whilst a skilled man can sit in his study in the winter time and picture to himself a new bean or muskmelon, and then go out in the next three or four summers and produce it.

9. *If it is desired to employ crossing as a direct means of producing new varieties, each parent to the proposed cross should be selected in agreement with the rules already specified, and also because it possesses in an emphatic degree one or more of the qualities which it is desired to combine; and the more uniformly and persistently the parent presents a given character, the greater is the chance that it will transmit that character.* It has already been said that crossing for the instant production of new varieties is most certain to give valuable

enough seed to give a thousand trees. At the end of ten years, all the seedlings had perished (this was in Minnesota) except one hardy seedling crab. Then a small lot of seeds of apples and crab apples was obtained in Maine, and from these the Wealthy came. There were only about fifty seeds in the batch of crab seed which gave the Wealthy; but before this variety was obtained, much over a bushel of seed had been sown.

results in those species which are propagated by buds, because the initial individual differences are not dissipated by seed-reproduction. This is especially true of hybridization, or crossing between distinct species; for in such violent crossing as this the offspring is particularly likely to be unstable when propagated by seeds. The results of hybridization appear to be most certain in those plants which are grown under glass, and in which, therefore, the selection of the seed-parents is most carefully made, and where the conditions of existence are most uniform. The most remarkable results in hybridization which have yet been attained are with the choicer glass-house plants, such as orchids, begonias, anthuriums, and the like. (Lecture II.)

The more violent the cross, the less is the likelihood that desirable offspring will follow. Species which refuse to give satisfactory results when hybridized directly or between the pure stocks, may give good varieties when the "blood" has become somewhat attenuated through previous crossings. The best results in hybridizing our native grape with the European grape, for example, have come from the use of one parent which is already a hybrid. Two notable examples are the Brighton and Diamond grapes, raised by Jacob Moore. The Brighton is a cross of Concord (pure native) by Diana-Hamburg (hybrid of impure native and European). Diamond is a cross of Concord by Iona, the latter parent undoubtedly of impure origin, containing a trace of the European vine. T. V. Munson's Brilliant is a secondary hybrid, its parents, Lindley and Delaware, both containing hybrid blood. Others of his varieties have similar histories. Even when the cross is much attenuated — or three or four or even more times removed from a pure hybrid origin by means of subsequent crossings — it may still produce marked effects in a cross without introducing such contradictory characters as to jeopardize the value of the offspring.

Amongst American fruit plants there are comparatively few valuable hybrids. The most conspicuous ones are in the grapes, particularly the various Rogers varieties, such as Agawam, Lindley, Wilder, Barry, and others, which are hybrids of the European grape and a native species. Other hybrids are the Kieffer and allied pears (between the common pear and the Oriental pear), the Transcendent and a few other crabs (between the common apple and the Siberian crab), the Soulard and kindred crabs (between the common apple and the native Western crab), a few blackberries of the Wilson Early type (between the blackberry and the dewberry), the purple-cane raspberries (between the native red and black raspberries, and possibly sometimes combined with the European raspberry), the Utah Hybrid cherry (between the Western sand cherry and the sand plum), and probably a few of the native plums. There is undoubtedly a fertile field for further work in hybridizing our fruits, particularly those of native origin, and also many of the ornamental plants; the danger is that persons are apt to expect too much from hybridization, and too little from the betterment of all the other conditions which so profoundly modify plants. Violent hybridizations generally give unsatisfactory and unreliable results; but subsequent crossings, when the "blood" of the original species to the contract is considerably attenuated, may be expected to correct or overcome the first incompatibility, as explained above.

10. *Establish the ideal of the desired variety firmly in the mind before any attempt is made at plant-breeding.* If one is to make any progress in securing new varieties, he must first be an expert judge of the capabilities and merits of the plants with which he is dealing, otherwise he may attempt the impossible or he may obtain a variety which has no merit. It is important, too, that the person bear in mind the fact that a variety which is simply as good as any other in cultivation is not worth introducing. It should be better in some particular than any other in existence. The operator must know the

points of his plant, as an expert stock-breeder knows the points of an animal, and he must possess the rare judgment to determine which characters are most likely to reappear in the offspring. Inasmuch as a person can be an expert in only a few plants, it follows that he cannot expect satisfactory results in breeding any species which may chance to come before him. Persistent and uniform effort, continued over a series of years, is generally demanded for the production of really valuable varieties. Thus it often happens that one man excels all competitors in breeding a particular class of plants. The horticulturist will recall, for instance, Lemoine in the breeding of gladiolus, Eckford in peas, Crozy in cannas, Bruant in pelargoniums, and others. There are now and then varieties which arise from no effort, but because of that very fact they reflect no credit upon the so-called originator, who is really only the lucky finder. So far as the originator is concerned, such varieties are merely chance. If, however, the operator — himself an expert judge of the plant with which he deals — chooses his seeds with care and discrimination, and then proposes, if need be, to follow up his work generation by generation by means of selection, the work becomes plant-breeding of the highest type.

First of all, therefore, the operator must know what he can likely get, and what will likely be worth getting. Most persons, however, begin at the other end of the problem, — they get what they can, and then let the public judge if the effort has been worth the while.

11. *Having obtained a specific and correct ideal, the operator must next seek to make his plant vary in the desired direction.* This may be done by crossing, or by modifying the conditions under which the plant grows, as indicated in Lectures I. and II. If there are any two plants which possess indications of the desired attributes, cross them: amongst the seedlings there may be some which may serve as starting-points for further effort.

A change in the circumstances or environment of the plant may start the desired attribute. If the plant must be dwarfer, plant it on poorer or drier soil, transfer it towards the poles, plant it late in the season, or transplant it repeatedly (see pages 25 and 143). Dwarf peas become climbing peas on rich, moist soils. If the plant must have large fruits, allow it more food and room, and give attention to pruning and thinning. Certain geographical regions develop certain characters in plants, as we have seen (page 24); if, therefore, the desired feature does not appear spontaneously or as a result of any other treatment, transfer the plant for a time to that region which is characterized by such attributes, if there is any such.

The importance of growing the plant under conditions or environments in which the desired type of characters is most frequently found, is admirably emphasized in the evolution of varieties which are adapted to forcing under glass. Within a century,—and in many instances within a decade or two,—species which were practically unknown to glass-houses have produced varieties which are perfectly adapted to them. This has been accomplished by growing the most tractable existing varieties under glass, and then carefully and persistently selecting those which most completely adapt themselves to their environment and to the ideals of the operator. One of the most remarkable examples of this kind is afforded by the carnation. In Europe it is chiefly a border or out-door plant, but within a generation it has produced hosts of excellent forcing varieties in America, where it is grown almost exclusively as a glass-house flower. So the carnation types of Europe and America are widely unlike, and the unlikeness becomes more emphatic year by year because of the rapid aberrant evolution of the American forms.

Sowing the seeds of hardy annual plants in the fall often generates a tendency to produce thickened roots. The plant, finding itself unable to perfect seeds, stores its reserve in the root, and it therefore tends to become biennial. In this manner, with the aid of selection and the variation of the soil, Carrière was able to produce good radishes from the wild slender-rooted charlock (Raphanus Raphanistrum).

Lessened vigor, so long as the plant continues to be healthy, nearly always results in a comparative increase of fruits or reproductive organs. It is an old horticultural maxim that checking growth induces fruitfulness. It is largely in consequence of this fact that plants bear heaviest when they attain approximate maturity. Trees are often thrown into bearing by girdling, heavy pruning, the attacks of borers, and various accidental injuries. The gardener knows that if he keeps his plants in vigorous growth by constantly potting them on into larger pots, he will get little, or at least very late, bloom. The plant-breeder, therefore, may be able to induce the desired initial variation by attention to this principle. (See discussion of variation in relation to food supply, page 16.) Arthur has recently put the principle into this formula: "A decrease in nutrition during the period of growth of an organism, favors the development of the reproductive parts at the expense of the vegetative parts."

A most important means of inducing variation is the simple change of seed, the philosophical reasons for which are explained on pages 59 and 28. A plant becomes closely fitted or accustomed to one set of conditions, and when it is placed in new conditions, it at once makes an effort to adapt itself to them. This adaptation is variation. No doubt the free interchange of seeds between seed-merchants and customers is one of the most fertile causes of the enormous increase in varieties in recent times.

When once a novel variety appears, others of a similar kind are likely soon to follow in other places, and some persons have supposed that there is a synchronistic variation in plants, or a tendency for like variations to appear simultaneously in widely separated localities. There is perhaps some remote reason for this belief, because there is, as Darwin expresses it, an accumulative effect of domestication or cultivation, by virtue of which plants which long remain comparatively invariable may within a short time, when cultivation has been continued long enough, vary widely and in many directions; and it is to be expected that even when plants have long since responded to the wishes of the cultivator, an equal amount or accumulation of the force of domestication would tend to produce like effects in different places. But it is probable that by far the greater part of this synchronistic variation is simply an apparent one, for whenever any marked novelty appears the attention of all interested persons is directed to looking for similar variations amongst their own plants.

12. *The person who is wishing for new varieties should look critically to all perennial plants, and particularly to trees and shrubs, for bud-varieties or sports.* It has already been said (pages 28, 6) that the branches of a tree may vary amongst themselves in the same way in which seedlings vary, and for the same reasons. As a rule, any marked sport is capable of being perpetuated by bud-propagation. The number of bud-varieties now in cultivation is really very large. Many of the cut-leaved and colored or variegated varieties of ornamental plants were originally found upon other trees as sports. The " mixing in the hill " of potatoes is bud-variation. Nectarines are derived from the peach, some of them as sports and some as seedlings. The moss-rose was probably originally a sport from the Provence rose. Greening apple trees often bear russet apples, and russet trees sometimes bear greenings. So far as I know, there are no varieties of annual plants which have originated as sports. The probable reason for this is the fact that the duration of the plant is short and that its constitution is not profoundly modified in a single generation by the new circumstances in which it is placed every

year. The effects of the conditions in which it lives are recorded in the seeds, and the plant dies without allowing a second season of growth to express the impressions which were received in a former generation. The fact that every branch of an annual plant — as of perennials — is unlike every other branch, is evidence enough that the annual is not unlike the perennial in fundamental constitution; and there is every reason to believe that if any given annual were to become a perennial, it would now and then develop differences sufficiently pronounced to make them worthy the name of sports, the same as hyacinths, bouvardias, trees, and all other perennial plants are apt to do.

Bud-varieties may not only come true from buds — as grafts, cuttings and layers, — but they occasionally perpetuate themselves by seeds. Now, these seedlings are amenable to selection, just the same as any other seedlings are; the bud-variety, therefore, may give the initial starting-point for plant-breeding. But, more than this, it is sometimes possible to improve and fix the type by bud-selection as well as by seed-selection. Darwin cites this interesting testimony: "Mr. Salter brings the principle of selection to bear on variegated plants propagated by buds, and has thus greatly improved and fixed several varieties. He informs me that at first a branch often produces variegated leaves on one side alone, and that the leaves are marked only with an irregular edging, or with a few lines of white and yellow. To improve and fix such varieties, he finds it necessary to encourage the buds at the bases of the most distinctly marked leaves and to propagate from them alone. By following, with perseverance, this plan during three or four successive seasons a distinct and fixed variety can generally be secured." Ernest Walker, a careful gardener at New Albany, Indiana, is of the opinion that the abnormal character of sports often intensifies itself if the sport is allowed to remain upon the parent plant for a considerable time. He has observed this particularly in coleus, where color sports are frequent. "In these," he says, "the sport begins with a branch, which may be taken off and propagated as a new variety. If left on the parent, other parts of the plant are apt to show similar variations. Indeed, I think it is not best to be in too great a hurry to remove a sporting branch, for its character seems to tend to become more fixed if it remains on the plant."

13. *The starting-point once given, all permanent progress lies in continued selection.* This, as I have already pointed out, is really the key to the whole matter. In the greater number of cases, the operator cannot produce the initial variation which he desires, but, by looking carefully amongst many plants, he may find one which shows an indication

of his ideal. This plant must be carefully saved, and all the seeds sown in a place where crossing with other types cannot take place. Of a hundred seedlings from this plant, mayhap one or two will still further emphasize the character which is sought. These, again, are saved and all the seeds are sown. So the operation goes on, patiently and persistently, and there is reward at the end. This is the one eternal and fundamental principle which underlies the amelioration of plants under the touch of man; and because we know, from experience, that it is so important, we are sure, as Darwin was, that selection in nature must be the most potent factor in the progress of the vegetable world.

But suppose this suggestion of the new variety does not appear amongst the batch of plants which we raise? Then sow again; vary the conditions; select the most widely variable types; cross; at length — if the ideal is true — the suggestion will come. "Cultivation, diversification of the conditions of existence, and repeated sowings" are the means which Verlot would employ to induce variations. But the skill and the character of the final result lie not so much in the securing of the initial start, as in the subsequent selection. Nature affords starting-points in endless number, but there are few men alert and skilful enough to take the hint and improve it. If I want a new tomato, I first endeavor to discover what I want. I decide that I must have one like the Acme in color, but more spherical, with a firmer flesh, and a little earlier. Then I shall raise an acre of Acme tomatoes, and closely allied varieties; or if I cannot do that, I make arrangements to inspect my neighbor's fields. I scrutinize every plant as the first fruits are ripening. Finally, I find one plant — not one fruit — which is something like the variety which I desire. Very well! Wait two to five years, and you shall see my new variety!

Some of these initial variations possess no tendency to reproduce themselves. The seedlings of them may break up into a great diversity of forms, no form representing the parent closely. In such cases, it is generally useless to proceed further with this brood. Another start should be made with another plant. So it is always important, as we have already seen (Rule 6), to have as many starting-points as possible, to lessen the risk of failure. Whilst it requires nice judgment to select those plants which possess the most important and the most transmissible combination of characters, the greatest skill is nevertheless required to carry forward a correct system of selection.

14. *Even when the desired variety is obtained, it must be kept up to the standard by constant attention to selection.* That is, there is no real stability in

the forms of plant life. So long as the conditions of existence vary, so long will plants make the effort to adapt themselves to the changes. No two seasons are alike, and no two fields, or even parts of fields, are alike; and there are no two cultivators who give exactly the same and equal attention to tillage, fertilizing, and the other treatments of plants. All forms or varieties, therefore, tend to "run out" by variation or gradual evolution into other forms; but because we keep the same name for all the succeeding generations, we fancy that we still have the same variety. In 1887 I found a single tomato plant in my garden in Michigan, which had several points of superiority over any other of the one hundred and seventy varieties which I was then growing. It came from a packet of German seed of an inferior variety. The tomato was very solid, an unusually long keeper, productive, and attractive in size and appearance. The variation was so promising that I named it in a sketch of tomatoes which I published that year, calling it the Ignotum (that is, *unknown*), to indicate that the origin of it was no merit of my own. I sent seeds to a few friends for testing. I sowed the seeds for about five hundred plants in 1888 in an isolated patch upon uniform soil. The larger part of the plants were more or less like the parent. A few reverted. A few of the best plants were selected, and the seed saved. I then moved to New York and took the seed with me. This was sown in uniform soil in an isolated position in 1889. This crop, probably as a result of the careful selection of the year before and of the change of locality, was remarkably uniform and handsome. Of the 442 plants which I grew that year, none reverted to the little Eiformige Dauer, the German variety from which it had come, but there was some variation in them due to different methods of treatment. I again saved the seeds, and I was now ready to introduce the variety. I therefore sold my seed, six pounds, to V. H. Hallock & Son, Queens, New York, who introduced it in 1890. The very next year, 1891, I obtained the Ignotum from fifteen dealers and grew the plants side by side. Of the fifteen lots, eight bore small and poor fruits which were not worth growing and which could not be recognized as Ignotum! Grown from our own seed, it still held its characters well. Here, then, only a year after its introduction, half the seedsmen were selling a spurious stock. It is possible that some of this variation arose from substitution of other varieties by seedsmen, although I have yet secured no evidence of any unfair dealing. It is possible, also, that the product of some of the samples which I early sent out for testing had found their way into seedsmen's hands. But I am convinced that very much of this variation was a legitimate result of the various conditions in which the crops of 1890 had been grown, and the varying ideals of those who saved the seeds. I am the more positive of this from the fact that the Ignotum tomato, as I first knew it and bred it, appears to be lost to cultivation, although the name is still used for the legitimate family of descendants from my original stock. All this experience illustrates how quickly varieties pass out by variation and by the unconscious and unlike selection practised by different persons.

The duration of any variety is inversely proportional to the frequency of its generations. Annual plants, other conditions being the same, run out sooner than perennials, because seed-reproduction — or the generations — intervenes more frequently. Trees, on the other hand, carry their variations longer, because the seed-generations — in which departures chiefly take place — are farther apart. Of all the so-called fruit plants, the strawberry runs out soonest and the varieties change the oftenest, because a new generation can be brought into fruit-bearing in two years, whilst it may require a decade or more to bring a new generation of apples or chestnuts into bearing. Yet, my reader will remind me that the Wilson strawberry has been and is the leading variety in many places for nearly forty years, to which I reply that the Wilson of to-day is not necessarily the same as that introduced by James Wilson, simply because the name is the same. Every different soil or treatment tends to produce a different strain or variation in the Wilson strawberry, as it does in any other plant ; and every grower, when setting a new plantation, selects his plants from that part of his field which pleases him best, rather than from those plants which most nearly correspond to the original type of the Wilson. That is, this unconscious selection on the part of the grower takes no account of what the variety was, but only of what it ought to be, and this ideal differs with every person. It is not surprising, therefore, to find strains of Wilson strawberry which are as unlike as many named varieties are ; and it is to be expected that all of the strains now in existence have departed considerably from the original type.

This example borrowed from the strawberry is a most important one, because it illustrates how a variety may vary and pass out of existence even though it is propagated wholly asexually, or by buds. There are to-day several different types of Rhode Island Greening apple in cultivation, which have originated from variations produced by environment and by the different models which propagators have had in mind ; and the same is true of many other fruits.

All the foregoing remarks demonstrate the importance of constant attention to selection if one desires to maintain the exact type of any variety which he has produced. They explain the value of the "roguing" — or systematic destruction of all "rogues" or non-typical plants — which is invariably practised by all good seed-growers. But they still more emphatically show that every variety is essentially unstable, and that the only abiding result is constant evolution, the old forms being left behind as the type expands into new and better strains. Varieties to be valuable, therefore, ought not to be rigidly fixed, and, fortunately, nature has prescribed that they cannot be. Probably every decade sees a complete change in every variety of any annual species which is propagated exclusively from seeds, and every century must see a like change in the tree fruits. These changes are so gradual, and the original basis of comparison fades away so completely, that we generally fail to recognize the evolution.

15. *It is evident, therefore, that the most abiding progress in the amelioration of plants must come as a result of the very best cultivation and the most intelligent selection and change of seed.* Every reflective person must admit that the cultivation of plants — which is the fundamental conception of agriculture — has been and is crude and imperfect,

and that there has been no conscious effort on the part of the human race to produce any given final result upon the cultivated flora. Yet, this imperfect cultivation has already modified plants so profoundly that we cannot determine the originals of many of them, and we can trace the evolution of but few. The science of rural industry is now fairly well understood in its essential fundamental principles, and the intelligence of those classes of persons who deal with plants is rapidly enlarging. The opening of the twentieth century will virtually mark a new era for agriculture, and from that time on the onward evolution of plants should proceed confidently and unchecked. Our eyes are too often dazzled by the novelties which suddenly thrust themselves upon us, and we look for some mystic power which shall enable us to produce varieties forthwith at our will. We need not so much varieties with new names as we do a general increase in productiveness and efficiency of the types which we already possess ; and this augmentation must come chiefly in the form of a gradual evolution under the stimulus of good care. The man who will accomplish most for the amelioration and unfolding of the forms of plants, is he who fixes his eyes steadily upon the future, and with the inspiration of a long forecast, urges the betterment of all conditions in which plants grow.

III. SPECIFIC EXAMPLES.

The foregoing principles and discussions will become more concrete if a few actual examples of the origination of varieties are given. In order to begin with a very simple case, I will relate the introduction of the varieties of dewberries, for this fruit is yet little cultivated, the varieties are few, and the domestication of it is not yet thirty years old.

The Dewberry and Blackberry.

The dewberries are native fruits, and it is only within the last ten years that they have become prominent among fruit-growers. The most important one is the Lucretia. This was found growing wild upon a plantation in West Virginia in war time. In 1876, a few of the plants were sent to Ohio, and from this start the present stock has come. It is probable that similar wild varieties are growing to-day in many parts of the country, but they have not chanced to have been seen by persons who are interested in cultivating them. It is a form of the common wild dewberry, which grows all over the northeastern states. Just why this particular patch in West Virginia should have been so much better than the general run of the species, nobody knows, but it was undoubtedly the product of some local environment of soil or position.

Early in the seventies, T. C. Bartel, of Huey, Clinton Co., Illinois, observed very excellent dewberries growing in rows between the lines of stubble in an old cornfield, where the plant had evidently been quick to avail itself of unoccupied land. This was introduced as the Bartel dewberry, and is now the second in point of prominence amongst the cultivated varieties. Other varieties have appeared in much the same way. A fruit-grower in Michigan found an extra good dewberry in a neighboring wood-lot, and introduced it under the name of Geer, in compliment to the owner of the place. In Florida, an unusually good plant of the common wild dewberry of that region was discovered, and introduced by Reasoner Brothers, under the name of Manatee. There are now about twenty named varieties of dewberries in cultivation, as described in our horticultural writings, all of which, so far as I know, are chance plants from the wild.

As the dewberries become more widely grown, good seedlings will now and then appear in cultivated ground, and these will be named and sold. After a time persons will begin to sow seeds for the purpose of producing new varieties; and those seedlings which chance to possess unusual merit will be propagated, and in due time introduced. This is the history of the cultivated blackberries and raspberries which have come from the wild plants in less than half a century. These fruits are now so far developed that we no longer think of looking to the woods and copses for new varieties of promise, but the novelties are mostly chance seedlings from cultivated varieties. A few years ago a friend purchased plants of the Snyder blackberry. When they came into bearing he noticed that one plant was better than the rest. It bore larger fruits, and the bearing season was longer. He took suckers from this plant, and from these others were taken, until he now has a large plantation of the novelty, mostly selected from plants which pleased him best. The variety has such distinct merit that I have named it the Mersereau, in honor of the man who recognized and propagated it. He will continue selecting from the best plants, as he propagates year by year, and it may be that in a few years he will have so much improved it that it will no longer be the variety with which he started.

The Apple.

The original apple is not definitely known, but it was certainly a very small and inferior, crabbed fruit, borne mostly in clusters. When we first find it described by historians, it was still of small value. Pliny said that some kinds were so sour as to take the edge off a knife. But better and better seedlings continued to come up about habitations, until, when printed descriptions of fruits began to be made, three or four hundred years ago, there were many named kinds in existence. The size had vastly improved, and with this increase came the reduction of the number of fruits in the cluster; so that, at the present time, whilst apple flowers are borne in clusters, the fruits are generally borne singly. That is, most of the flowers fail to set fruit, and they complete their mission when they have shed their pollen for the benefit of the one which persists.

The American colonists brought with them the staple varieties of the mother countries. But the needs of the new country were unlike those of the old, and the tastes and fashions of the people were changing. So, as seedlings came up about the buildings and along the fences, where the seeds had been scattered, the ones which promised to satisfy the new needs best were saved, and many of the old varieties were allowed to pass away. In 1817, the date of the first American fruit-book, over sixty per cent of the varieties particularly recommended for cultivation in this country were of American origin. In 1845, nearly two hundred varieties of apples were described as having been fruited in this country, of which over half were of American origin. Between these two dates, introductions of foreign varieties had been freely made, so that the percentage of domestic varieties had fallen. But the next thirty years saw a great change. Of 1823 varieties described in 1872, nearly or quite seventy per cent were American, and a still greater proportion of the most prized kinds were of domestic origin. In the older states, the apple had now become so thoroughly accustomed to its environment, and the tastes of the people were so well supplied, that there was no longer much need for the introduction of foreign kinds. It was not so in the Northwest. There the apples of the eastern states did not thrive. The climate was too cold and too dry. Attention was turned to other countries with similar or rigorous climate. In 1870, the Department of Agriculture at Washington imported cions of many varieties of apples from Russia; but these did not satisfy many fruit-growers of the northern states. It was then conceived that the great interior plain of Russia should yield apples adapted to the upper Mississippi valley, whilst those already imported had come from the seaboard territory. Accordingly, early in the eighties, Charles Gibb, of the province of Quebec, and Professor Budd, of Iowa, went to Russia to introduce the promising fruits of the central plain. The result has been a most interesting one to the pacific looker-on. There are ardent advocates of the Russian varieties, and there are others who see nothing good in them. There are those who believe that all progress must come by securing seedlings from the hardiest varieties of the eastern states; there are others who would derive everything from the Siberian crabs, and still others who believe that the final result lies in improving the native crabs. There is no end of discussion and cross-purposes. In the meantime, nature is quietly doing the work. Here is a good seedling of some old variety, there a good one from some Russian, and now and then one from the crab stocks. The new varieties are gradually supplanting the old, so quietly that few people are aware of it; and by the time the contestants are done disputing, it will be found that there are no Russians and no eastern apples, but a brood of northwestern apples which have grown out of the old confusion.

All these new apples are simply seedlings, almost all of them chance trees which come up here and there wherever man has allowed nature a bit of ground upon which to make garden as she likes. In 1892, there were 878 varieties of apples offered for sale by American nurserymen, and it is doubtful if one in the whole lot was the result of any attempt on the part of the originator to produce a variety with definite qualities. And what is true of the apple, is about equally true of the other tree fruits. In the small fruits and the grapes, where the generations are shorter and the results quicker, more has been done in the way of direct selection of seeds and the crossing of chosen parents; but even here, the methods are mostly haphazard.

Beans.

Perhaps there are no plants more tractable in the hands of the plant-breeder than the garden beans. Some two or three years ago, a leading eastern seedsman conceived of a new form of bean pod which would at once commend itself to his customers. He was so well convinced of the merits of this prospective variety, that he made a descriptive and "taking" name for it. He then wrote to a noted bean-raiser, describing the proposed variety and giving the name. "Can you make it for me?" he asked. "Yes, I will make you the bean," replied the grower. The seedsman then announced in his catalogue that he would soon introduce a new bean, and, in order to hold the name, he published it, along with the announcement. Two years later, I visited the bean-grower. "Did you get the bean?" I asked. "Yes, here it is." Sure enough, he had it, and it answered the requirements very well. Another seedsman would like a round-podded, stringless, green-podded bean. This same man produced it, and I went into a field of fifteen acres of it, where it was growing for seed, and the most fastidious person could not have asked for a closer approach to the ideal which the breeder had set before him some four or five years before.

How is all this done? It looks simple enough. The ideal is established first of all. The breeder revolves it in his mind, and eliminates all the impracticable and contradictory elements of it. Then he goes carefully and critically through his bean fields, particularly those varieties which are most like the desired kind, and marks those plants which most nearly approach his ideal The seeds of these are carefully saved, and they are planted in isolated positions. If he finds no promising variations amongst his plantations, then he must start off the variation in some other way. This is usually done by crossing those varieties which are most like the proposed kind. He has got a start; but now the science and skill begin. Year by year he selects just those plants which please him best and which he judges, from experience, will most surely carry their features over to the offspring. He starts with one plant; the next year he may have only two. If he has ten or twenty good ones, then the task is an easy one, for the variety has elements of permanence — that is, of hereditability — in it. But he may have no plants the second year. In that case, he begins again; for if the ideal is true, it can be attained. This bean-breeder to whom I have referred, and upon whom many of our best seedsmen rely for new varieties, tells me that he has discarded fully three thousand varieties and forms as profitless. This only means that he is a most astute judge of beans, and that he knows when any type is likely to prove to be a poor breeder.

The bean also affords an excellent example of the care which it is generally necessary to exercise to keep any variety true to the type. The person of whom I have spoken, in common with all careful seed-growers, searches his field with great pains to discover the "rogues," or those plants which vary perceptibly from the type of the given variety. The rogue may be a variation in size or habit of plant, season of maturity, color or form of pods, productiveness, susceptibility to rust, or other aberrance. In the dwarf or bush beans, which are now most exclusively grown, the most frequent rogue is a climbing or half-climbing plant. This is a reversion to the ancestral type of the bean, which was no doubt a twining plant. This rogue is always destroyed, even though it may be, itself, a good bean. In some cases, the men who perform the roguing are sent along every row of a whole field on their hands and knees, critically examining every plant. The effect of this continual selection is always to push on the variety to greater excellence. The various "improved" strains of plants are obtained in essentially this fashion. If the grower has been painstaking with his roguing, he soon finds that his seed gives better and more uniform crops than the common stock of the variety. If the improvement is marked, he may dignify his strain with a distinct name, and it thereby becomes a new variety. The improvement may be a very important one to a careful bean-grower, and at the same time be so slight as to escape the attention of the general farmer, or even of experimenters who are not particularly skilled in judging the merits of beans.

All these examples drawn from the bean are excellent illustrations of the best and most scientific plant-breeding, and the same methods — varied to suit the different needs — apply to the amelioration of all other plants. The recent dwarf Lima beans may be cited as examples of accidental or fortuitous varieties, in which the preconstructed ideal of the plant-breeder had no place. Four or five of these beans have attained some prominence. Henderson and Kumerle dwarf Limas were introduced in 1889, Burpee in 1890, and Barteldes in 1892 or 1893. The variety which is now called the Henderson was picked up twenty or more years ago by a negro, who found it growing along a roadside in Virginia. It was afterwards grown in various gardens, and about 1885 it fell into the hands of a seedsman in Richmond. Henderson purchased the stock of it in 1887, grew it in 1888, and offered it to the general public in 1889. The introduction of Henderson's bean attracted the attention of Asa Palmer, of Kennett Square, Pennsylvania, who had also been growing a dwarf Lima. He called upon Burpee, the well-known seedsman of Philadelphia, described his variety, and left four beans for trial. These were planted in the test grounds and were found to be valuable. Mr. Palmer's entire stock was then purchased, — comprising over an acre, which had been carefully inspected during the season — and Burpee Bush Lima was presented to the public in the spring of 1890. Mr. Palmer's dwarf Lima originated in 1883, when his entire crop of Large White (Pole) Limas was destroyed by cut-worms. He went over his field to remove the poles before fitting the land for other uses, but he found one little plant, about ten inches high, which had been cut off about an inch above the ground but which had re-rooted. It bore three pods, each containing one seed. These three seeds were planted in 1884, and two of the plants were dwarf, like the parent. By discarding all plants which had a tendency to climb, in succeeding crops, the Burpee Bush Lima, as we now have it, was developed. The Kumerle, Thorburn, or Dreer, Dwarf Lima originated from occasional dwarf forms of the Challenger Pole Lima, which J. W. Kumerle, of Newark, New Jersey, found growing in his field. The stock which came from these selected dwarf plants was introduced by Thorburn and Dreer, under their respective names. The singular Barteldes Bush Lima came from Colorado, and is a similar dwarf sport of the old White Spanish or Dutch Runner bean. Barteldes received about a peck of the seed and introduced it sparingly. It attracted very little attention, and as the following season was dry, Barteldes himself failed to get a crop, and the variety was lost to the trade.

Cannas.

Few plants have shown more remarkable evolutions in very recent years than the cannas. At the present time, the Crozy cannas — so named from Crozy, of Lyons, France, who has introduced the greater number of them — are most popular. This type is often called the French Dwarf, or the Flowering Canna, and it is marked by a comparatively low stature, and very large and showy spreading flowers in many colors, whereas the cannas of a few years ago were very tall plants, with small and late dull red, narrow flowers, and they were grown exclusively for their foliage effects. How has this transformation come about?

In the first place, it should be said that there are many species of canna, and about a half dozen of these were well known to gardeners at the opening of the century. About 1830, the cannas began to attract much attention from cultivators, and the original species were soon variously hybridized. Crossed seeds, and seeds from the successive generations of hybrids, introduced a host of new and variable forms. The first distinct fashion in cannas seems to have been for tall, late-flowering forms. In 1848, Année, a cultivator in France, sowed seeds of Canna Nepalensis, a tall oriental species, and there sprung up a race of plants which has since been known as Canna Annæi. It is probable that this Canna Nepalensis had become fertilized with other species growing in Année's collection, very likely with Canna glauca. At any rate, this race of cannas became popular, and was to its time what the French dwarfs are to the present day. The plants were freely introduced into parks, beginning about 1856, but their use began to wane by 1870 or before. Descendants of this type, variously crossed and modified, are now frequently seen in parks and gardens.

The beginning of the modern race of dwarf, large-flowered cannas was in 1863, when one of the smaller-flowered Costa Rican species (Canna Warscewiczii) was crossed upon a large-flowered

Peruvian species (Canna iridiflora). The offspring of this union came to be called Canna Ehemanni. This hybrid has been again variously crossed with other species, and modified by cultivation and selection, until the present composite type is the result. Seeds give new varieties; and any seedling which is worth saving is thereafter multiplied by divisions of the root, and the resulting plants are introduced to commerce.

These various examples are but types of what has been and can be accomplished in a given group of plants. There is nothing mysterious about the subject, so far as the cultivator is concerned. He simply sets his ideal, makes sure that it does not contradict any of the fundamental laws of development of the plant with which he is to work, then patiently and persistently keeps at his task. He must have good judgment, skill, and inspiration, but he does not need genius.

"In the improvement of plants," writes Henri L. de Vilmorin, "the action of man, much like influences which act on plants in the wild state, only brings about slow and gradual changes, often scarcely noticeable at first. But if the efforts toward the desired end be kept on steadily, the changes will soon become greater and greater, and the last stages of the improvement will become much more rapid than the first ones."

LECTURE IV.

RECENT OPINIONS: BEING A RÉSUMÉ OF THE INVESTIGATIONS OF DE VRIES, MENDEL, AND OTHERS, AND A STATEMENT OF THE CURRENT TENDENCIES OF AMERICAN PLANT-BREEDING PRACTICE.

In the first and second editions, Lecture IV. was devoted to "Borrowed Opinions," being extracts from representative European writings. The chapter contained a conspectus of Verlot's opinions respecting the production of varieties, as expressed in his "Sur la Production et la Fixation des Variétés dans les Plantes d'Ornement"; also a rather full transcript of Carrière's account of bud-varieties from his "Production et Fixation des Variétés dans les Végétaux"; and a translation of Focke's discussion of the characteristics of crosses from Chapter IV. of "Die Pflanzen-Mischlinge." Since 1895 a very great change of view has taken place in respect to all the matters discussed in those papers, although the vexed questions associated with bud-variation are not yet greatly elucidated. It has seemed best, therefore, to devote this chapter now to the recent opinions rather than to the older opinions. The idea of the "fixation of varieties"—as a chemist might speak of the fixation of gases or other substances—will not apply to plants. In fact, the production of mere "varieties" is a passing ideal, for we are now endeavoring to produce characters or units. Varieties are not entities, or real units. The point of emphasis has shifted. It is suggestive that the term "plant-breeding," rather than the "production of varieties," is now current, indicating that we now conceive primarily of a process: this process, when intelligently followed, may produce plants of new value.

I. SOME RECENT IDEAS ON THE EVOLUTION OF PLANTS.[1]

There is endless dissimilarity in nature. No two plants and no two animals are exactly alike. There are more plants and animals than can find a place in which to live and thrive. There results a struggle for existence. Those animals or plants which, by virtue of their individual differences or peculiarities, are best fitted to the conditions in which they are placed, survive in this struggle for existence. They are "selected" to live. Those that survive, propagate their peculiarities. By

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[1] Address before the Society for Plant Morphology and Physiology, Washington, December 29, 1902. Printed in *Science*, March 20, 1903, but now somewhat modified. The greater part of this essay that relates to the De Vriesian views was read and corrected in the manuscript by Professor de Vries.

virtue of continued variation, and of continual selection along a certain line, the peculiarities may become augmented ; finally the gulf of separation from the parental stem becomes great, and what we call a new species has originated.

This, in epitome, is the philosophy of Darwin in respect to evolution of organic forms. It contains the well-known postulate of natural selection, the principle that we know as Darwinism. This principle has had more adherents than any other hypothesis of the process of evolution. All recent hypotheses in some way relate to it. A number of them modify it, and some dispute it. The most pronounced counter-hypothesis is also the newest. It is that of Professor de Vries, botanist, of Amsterdam, who denies that natural selection is competent to produce species, or that organic ascent is the product of small differences gradually enlarging into great ones. According to De Vries's view, species-characters arise suddenly, or all at once, and they are ordinarily stable from the moment they arise.

a. *Variation: De Vries.*

De Vries conceives that variations, or differences, are of two general categories: (1) Variation proper, or small, fluctuating, unstable differences peculiar to the individual (only partially transmitted to offspring); and (2) mutations, or differences that are usually of marked character, appear suddenly and without transition to other forms and are at once the starting-points of new races or species. Variations proper may be due to the immediate environment in which the plant lives. The mutations are due to causes yet unknown, although these causes are considered to be physiological.

Natural selection works on both variations and mutations by eliminating the forms that are least adapted to persist. It is conceived to be a destructive, not a constructive or augmentative agency. It merely weeds out.

We may first consider selection with reference to variations proper. Among variations, or individual fluctuations, there may be a slight cumulative effect of selection, but it is incompetent ever to enlarge the differences into stable characteristics; and when natural selection ceases to act, the so-called variety falls back into its original form or splits up into other forms. Varieties of this kind are notably indefinable and unstable. It is impossible to "fix" them in any true sense; selection only preserves them, and when it is removed they perish as varieties. They are relatively only temporary and have no effect on phylogeny. Many of the minor adaptations of plants to the particular conditions in which they chance for the time being to be placed, are of this category. Much of the variation which results in acclimatization belongs here. The fluctuating horticultural varieties and gardeners' "strains" are of this kind. This discussion of the effect of cessation of selection recalls Weismann's panmixia, a name proposed to designate the breaking up of varietal or specific characteristics when natural selection ceases to act. Panmixia is not of itself an original force or an agency; it is merely a name for the results of all the forces or energies which are allowed to assert themselves when the restricting force of natural selection is removed. In De Vries's view, the progress made by selection must be maintained by selection.

We may next consider selection with reference to mutations. The mutations are practically stable or "fixed" the moment they arise. Of course there may be individual fluctuations or variations proper, amongst plants that have sprung from a mutated individual; but the main characteristics of the mutations are heritable. An organism is a complex of organs and attributes. Each attribute is a unit. From any unit a new unit may arise by mutation. The origination of a new unit constitutes at once a full and important character and marks the organism that possesses it as a new physiological species. Not only one unit, but any number of units, may give rise to mutations; and any one of these new mutations may give rise to other mutations. But the point is, that these mutations, be they great or small, arise by steps, are full formed when they arise, and do not grow or enlarge into other mutations. The mutations are multifarious (*all-seitig*), occurring apparently at random and in diverse directions, and without regard to fitness. They may be either quantitative or qualitative. Variations proper arise mostly in a definite line. Now, natural selection may weed out mutated individuals as it does mere variant individuals; and thus breaks may arise in the chain, and we have left what we know as taxonomic species.

Natural selection, with survival of the fittest, is, therefore, of two categories, at least so far as results are concerned,—that which operates within the species and results in the formation of local minor races, and that which operates between species and results in the formation of a line of ascent.

Everywhere and always plants are variable. Now and then and relatively rarely, plants are mutative. Any man who sees two plants, sees variation: there are no two plants alike. Only he who studies and observes critically, sees mutation. One must examine a hundred or a thousand or ten thousand individuals. In De Vries's extended experiments with *Œnothera*, only 1.5 per cent of the plants were mutative, and mutation is undoubtedly more common in cultivation than in the wild, and the mutated individuals are more likely to persist. The investigator should employ only statistical methods of comparison. He should contrast unit-characters rather than individuals as a whole. Moreover, not only are the numbers of mutating individuals relatively uncommon, but the species may not now be in a mutative epoch.

In other words, there are epochs in the history of the plant when mutations occur. These are the "mutation-periods" of De Vries. There are epochs of non-mutations, when no progress seems to be making. It may be conceived that some force is withholding or restraining the mutative impulse. This force is what we are in the habit of calling heredity. When heredity is overcome, there arises a "premutation-period," in which the mutations are beginning to express themselves; and eventually the full mutation-period may appear. Heredity and non-heredity, these are the ever opposing and ever contrasting forces in organic life, the one resulting in the survival of the like, the other resulting in the survival of the unlike. One is heredity; the other is variation. One makes for continuity; the other for evolution. No hypothesis of the energy of evolution is perfect that does not account for both. A theory of heredity, or continuity, must also account for the opposite of itself. It is not easy to construct a hypothesis or a metaphor that will accomplish this.

The phenomena of continuity and discontinuity were well contrasted by Korschinsky. These phenomena, he conceived, are the results of two antagonistic tendencies. Under normal or usual conditions heredity is the stronger force. The tendency to vary is always present, being predisposed by environment but not caused by it; when it gathers the necessary energy it overbreaks the power of inheritance and sudden variations or sports arise, and these sports are the starting-points of evolution. This discontinuous evolution is called by him heterogenesis.

The conceptions of *per saltum* variations of Korschinsky and De Vries seem to be practically identical. De Vries has carried his work further, into the realm of actual experimental investigation. He studied many species of plants in the hope of finding one or more that might be in its mutation-period. Finally, he chose the common evening primrose, *Œnothera Lamarckiana*, and by continual sowing of seeds and raising of great numbers of plants he discovered several truly mutative forms. These forms reproduce themselves by means of seeds as accurately as accepted species do. He has given some of them specific names. The full experimental history of them is given in the first volume of his brilliant work, "Die Mutationstheorie." These forms, he contends, are true elementary species. That is, they have new specific characters. These characters are heritable. It does not matter whether these characters are large or small — they become phylogenetic. These plants having the new specific characters may not be species in the Linnæan or historic or morphological sense, but they are real entities. We must give up the historical view of species when we study the evolution of organic forms. Historic or Linnæan species are taxonomic conceptions; the evolutional or elementary species are physiological conceptions.

The different categories of species, as respects their origin, are given as follows by De Vries: —

A. Origin by means of formation of new characters, or progressive species-origin.

B. Origin without formation of new characters.

1. By the becoming latent (*latentwerden*) of present characteristics, or retrogressive species-origin. Atavism in part belongs here.
2. By the becoming active (*activirung*) of latent characteristics, or degressive species-origin [*degress*, to come down from, to come out of].
    - (*a*) Taxonomic anomalies.
    - (*b*) True atavism.
3. By means of hybrids.

It will now be seen that the mutation theory of De Vries, which is in some respects a rephrasing and an extending of the old idea of sports, does not of itself introduce any new theory of the dynamics of evolution. It is not a theory of heredity nor of variation. His hypothesis of "intracellular pangenesis" carries the explanation of these phenomena one step further back, however. The plant cells give off pangenes. Each of these pangenes divides into two. Ordinarily, these two resemble the parent; but now and then one of them takes on a new character — the two become unlike — and gives rise to a mutation. This hypothesis, like Darwin's pangenesis, is useful as a graphic basis for discussion, whether or no it has real physiological foundation.

The most emphatic points of the mutation theory as they appeal to me are these: (1) It classifies variation into kinds that are concerned in evolution and kinds that are not; and thereby it denies that all adaptation to environment makes for the progress of the race. (2) It denies the power of natural selection to fix, to heap up, or to augment differences until they become truly specific. (3) It separates the results of struggle for existence and survival of the fittest into two categories, only one of which has an effect on phylogeny. (4) It asserts that evolution takes place by steps, and not by a gradual unfolding of one form into another, — that it is discontinuous rather than continuous. (5) It enforces the importance of critical comparative study of great numbers of individuals. (6) It challenges the validity of the customary conception of species as competent to elucidate the method of evolution.

There will arise confusion, in the forthcoming discussions of the theory of discontinuity, as to what is a species; but this confusion is not new. There are two conceptions of species: (1) As taxonomic groups, more or less arbitrarily made for purposes of classification; (2) as real things, marked by recordable differences however small or great, and conceived to be the actual steps in the phylogeny of the race. These categories are so distinct that they would not be confounded except for the unfortunate circumstance that we use one word (species) for the two. There has been a growing conviction that the two classes must be sharply separated when evolution questions are discussed. Nearly ten years ago I endeavored to combat the species-dogma from the garden point of view, as, in differing ways, others had done before ("Survival of the Unlike," Essay IV.). The confusion of the two conceptions expresses itself in the terminology of plant-breeding. Some writers define hybrid, for example, as a cross between species; this is the classificatory idea. Others define it to be any cross. The former use of the word is more proper merely because it is the historic use, originating as a systematist's concept. The latter idea should have been expressed by a new word. It is for this reason that I have held to the old or systematic definition of hybrid; but there is no appeal against usage, so, while still proclaiming the righteousness of my cause as an easement of my conscience, I strike my colors and henceforth use the word hybrid for a cross of any kind or degree. How often does mere language confuse us!

From an argumentative point of view, it will be difficult to determine, in a given case, just what are variations and what mutations, for these categories are separated not by any quantitative or qualitative characters — the "step" from one to the other may be ever so slight — but by the test that one kind is fully heritable and the other only partially so. If a mutation is to be defined as a heritable form, then it will be impossible to controvert the doctrine that evolution takes place by mutation, because the mutationist can say that any form that is inherited is by that fact a mutation. This will be equivalent to the position of those who, in the Weismannian days, denied the transmission of acquired characters, but defined an acquired character to be one that is not transmissible. However, it is to be hoped that the discussion of the mutation theory will not degenerate into a mere academic debate and a contention over definitions. Professor de Vries himself has set the direction of the discussion by making actual experiments the test of the doctrine. There will be confusing points, and times when we shall dispute over particular forms as to whether they are variations or mutations; but every one who has studied plants from the evolution point of view will be prepared to believe that species do originate by mutation. De Vries's work will have a profound and abiding influence on our evolution philosophies. For myself, I am a Darwinian, but I hope that I am willing to believe what is true, whether it is Darwinian or anti-Darwinian. My own belief is that species do originate by means of natural selection, but that not all species so originate.

b. *Heredity: Mendel.*

De Vries made a thorough search of the literature of plant evolution. In an American publication[1] he saw a reference to an article on plant

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[1] The following extract from a recent letter from Professor de Vries (printed here by permission) will explain the reference in the text: "Many years ago you had the kindness to send me your article on Cross-Breeding and Hybridizing of 1892; and I hope it will interest you to know that it was by means of your bibliography therein that I learnt some years afterwards of the existence of Mendel's papers, which now are coming to so high credit. Without your aid I fear I should not have found

hybrids by G. Mendel, published in 1865 in the proceedings of a natural history society of Brünn in Austria. On looking up this paper he was astonished to find that it discussed fundamental questions of hybridization and heredity, and that it had remained practically unknown for a generation. In 1900 he published an account of it, and this was soon followed by independent discussions by Correns, Tschermak, and Bateson. In May, 1900, Bateson gave an abstract of Mendel's work before the Royal Horticultural Society of England; and later the society published a translation of Mendel's original paper. It is only within the present year, however (1902), that a knowledge of Mendel's work has become widespread in this country. Perhaps the agencies that are most responsible for dissemination of the Mendelian ideas in America are the instruction given by Webber and others in the Graduate School of Agriculture at Columbus last summer, and the prolonged discussion before the International Conference on Plant-Breeding at New York last fall (1902). Lately, several articles on the subject have appeared from our scientific press.

them at all." My reference to Mendel in the bibliography referred to was taken from Focke's writing. I had not seen Mendel's paper. The essay, "Cross-Breeding and Hybridizing," forms Chapter II. of the present book; but the bibliography that accompanied it was not reprinted until the second edition of the book.

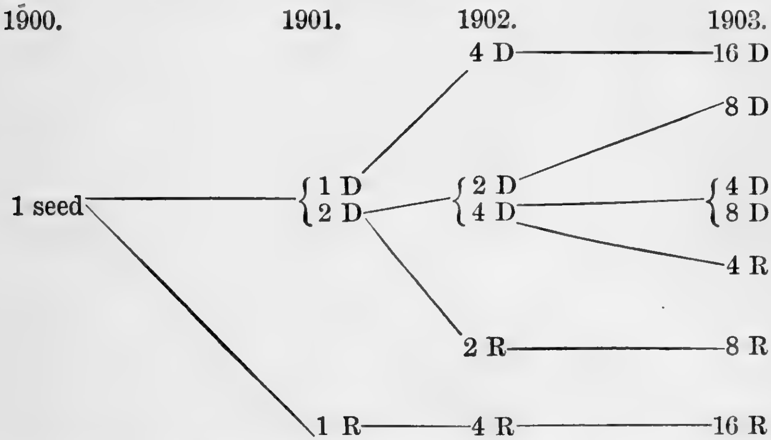
Mendel's work is important because it cuts across many of the current notions respecting hybridization. As De Vries's discussions call a halt in the current belief regarding the gradualness and slowness of evolution, so Mendel's call a halt in respect to the common opinion that the results of hybridizing are largely chance, and that hybridization is necessarily only an empirical subject. Mendel found uniformity and constancy of action in hybridization, and to explain this uniformity he proposed a theory of heredity.

One of the most significant points connected with Mendel's work is the great pains he took to select plants for his experiments. He believed that hybridism is a complex and intricate subject, and that, if we are ever to discover laws, we must begin with the simplest and least complicated problems. He was aware of the general belief that the most diverse and contradictory results are likely to follow any hybridization. He conceived that some of this diversity may be due to instability of parents rather than to the proper results of hybridizing. He also saw that he must exclude all inter-crossing in the progeny. Furthermore, the progeny must be numerous, for, since incidental and aberrant variation may arise in the plants, it is only by a study of averages of large numbers that the true results of the hybridizing are to be discovered. Moreover, the study must be more exact than a mere contrasting and comparing of plants: character must be compared with character.

The garden pea seemed to fulfil all the requirements. Mendel chose well-marked horticultural races or varieties. These he grew two years before the experiment proper was begun in order to determine their stability or trueness to type. When the experiments were finally begun, he used only normal plants as parents, throwing out such as were weak or aberrant. Peas are self-fertile. It was to be expected that under such conditions the hybrid offspring would show uniformity of action; and it did.

In order to study the behavior of the hybrids, it was necessary to choose certain prominent marks or characters for comparison. Seven of these characters were selected for observation. These marks pertain to seed, fruit, position of flowers, and length of stem, and they may be assumed to be representative of all other characters in the plant. These characters were paired (practically opposites), as long-stem *vs.* short-stem, round-seed *vs.* angular-seed, inflated-pod *vs.* constricted-pod. They were "constant" and "differentiating." Of course every parent plant possessed one or the other of every pair of contrasting characters; but in order to facilitate his studies, Mendel chose a special set of parents to illustrate each character, studying seed-shape in one set of hybrids, seed-color in another, pod-shape in another; in this way he avoided complication in the results. Since it is not my purpose to discuss Mendel's work in detail, but only the general significance of its results, as they appeal to me, I need not describe these characters here. It will be sufficient if I choose only one, the shape of the seed.

The seed-shape characters were roundness and angularity — the former being the "smooth" pea of gardeners and the latter the "wrinkled" pea. Let us suppose that twenty-five flowers on round-seeded plants were cross-pollinated in the summer of 1900 with pollen from angular-seeded plants, or *vice versa*, and that an average of four seeds formed in each pod. With the death of the parent plants the old generation ended, and the 100 seeds that matured in 1900 — the year in which the cross was made — began the next generation; and these 100 seeds were hybrids. Now, all these 100 seeds were round. Roundness in this case was "dominant." (Dominance pertaining to the vegetative stage of the plant of course would not appear until 1901, when the seeds "grow.") These seeds are sown in the spring of 1901. If each seed be supposed to give rise to four seeds — or 400 in all — this next generation of seeds (produced in 1901) will show 300 round and 100 angular seeds. That is, the other seed-shape now appears in one-fourth of all the progeny; this character is said to have been "recessive" in the first hybrid generation. If the 100 angular seeds, or recessives, are sown in 1902, it will be found that all the progeny will be angular-seeded or will "come true"; and this occurs in all succeeding generations providing no crossing takes place. If the 300 round seeds, or dominants, are sown in the spring of 1902, it will be found that 100 of them produce dominants only, and that 200 of them behave as before — one-fourth giving rise to recessives and three-fourths to dominants; and this occurs in all succeeding generations providing no crossing takes place. In other words, the three-fourths of dominants in any generation are of two kinds, — one-third that produce only dominants, and two-thirds that are hybrids. That is, there is constantly appearing from the hybrids one-fourth part that are recessives, one-fourth part that are constant dominants, and one-half part that are dominants to all appearances, but which in the next generation break up again into dominants and recessives. This one-half part that breaks up into the two characters are the true hybrids; but they are hybrids only in the sense that they hold each of the two parental characteristics — roundness and angularity — in their purity and not as blends or intermediates; and these two characteristics reappear in all succeeding generations in a definite mathematical ratio. Proportionally, these facts may be expressed as follows: —



It will be seen that two-thirds of the dominants break up the following year into one-fourth constant dominants, one-fourth recessives, and one-half that again break up, the half that break up being the hybrids. This formula for the hybrids is Mendel's law. In words, it may be expressed as follows: Differentiating characters in plants reappear in their purity and in mathematical regularity in the second and succeeding hybrid offspring of these plants; the mathematical law is that each character separates in each of these generations in one-fourth of the progeny and thereafter remains true. In concise figures, it is expressed as follows:

$$1\,D : 2\,DR : 1\,R.$$

M

1 *D* and 1 *R* come true, but *DR* breaks up again into dominants and recessives in the ratio of 3 to 1.

Mendel found that this law holds more or less for the other characters that he studied in the pea, as well as for the seed-shape. He did not conclude, however, that it holds good for all plants, but left the subject for further investigation. He himself found different results in *Hieracium.* It will be seen at once that it will be a very difficult matter to follow this law when many characters are to be contrasted, particularly when the characters are merely qualitative and grade into each other.

The dominant characters pertain to either parent: some of them may come from the mother and some from the father. When this roundness is dominant from the male parent, it falls under the domination of what we commonly know as xenia, or the immediate effect of pollen; when it is from the female parent, there is no xenia. In the case of the pea, the seed-content is embryo and we are not surprised if there is xenia. In those plants in which the embryo is embedded in endosperm, however, it would seem to be difficult to account for xenial dominance, unless there is double fecundation, as appears to be the case in Indian corn, as pointed out by De Vries, Webber,[1]

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[1] Bull. 22, Div. of Veg. Phys. and Path., U. S. Dept. Agric., 1900.

and others. It looks as if the question of dominance would introduce a new point of view into the study of xenia. At all events, the word xenia must be very clearly re-defined. There is now a strong tendency to restrict the use of the word to designate only those effects occurring in parts lying outside the embryo.

Which characters will be dominant in any species we cannot determine until we perform the experiment; that is, there is no mark or attribute which distinguishes to us *a priori* a dominant or a recessive character. However, the mere fact as to whether the one or the other character is dominant is relatively unimportant, for constant dominance is no more a regular behavior than recessiveness is. In various subsequent experiments it has been found that even when marked dominance is not shown in the first product, the hybridization may follow the law in essential numerical results. The really important points are: (1) That the characters typically remain pure or do not blend, and (2) that their reappearance follows a numerical order.

After finding such surprising results as these, Mendel naturally endeavored to discover the reasons why. The product of his speculations is the theory of gametic purity (to use our present-day terminology), which is a partial theory of heredity. Every plant is the product of the germ or female cell fertilized by the sperm or male cell. When constant progeny is produced it must be because the two cells, or gametes, are of like character. When inconstant progeny is produced, it must be because the sperm cell is of one character and the germ cell of another. When these unlike gametes come together they will unite according to the law of mathematical probabilities, one-fourth of those of each kind coming together and one-half of those of both kinds coming together. If A and B represent the contrasting parental characteristics, they would combine as —

$$\begin{gathered} A + A = A^2 \\ A + B = AB \\ B + A = BA \\ B + B = B^2 \end{gathered}$$

A^2 and B^2 are equivalent only to A and B. Since both of the opposed or contrasted characters cannot be visible at the same time, we have the following: —

$$\begin{gathered} A \\ A^b \\ A^b \\ B \end{gathered}$$

in which small b represents the character that for the time being is not able to express itself, or is recessive, and large B represents the same character fully expressed.

In these gametes the unit characters of the plants that bear them are pure. Even in hybrid plants the pollen grains and the egg cells are not hybrids. According to this hypothesis of gametic purity, therefore, hybrids follow natural and numerical laws; but these laws are always obscured by new crossing. True intermediate characters do not occur. If new characters appear, it is because they have been recessive or latent for a generation, or because the plant has varied from other causes; they are not the proper results of hybridization. We may suppose that a new character that appears because of effect of environment may be impressed on the gamete and thereby be perpetuated. The results of hybridization, according to the Mendelian view, are not fundamentally a mere game of chance, but follow a law of regularity of averages; but the results are so often masked that it is sometimes impossible to recognize the law.

It is a question, of course, whether the proportional results secured by Mendel and others express a biological principle, or whether they are only the numerical proportions that may be adduced from the averages of large numbers of combinations — whether these combinations are of gametes, or letters, or words, or figures. It is a fundamental necessity that certain proportions follow from "chance" combinations often repeated. But whether the "theorem of probabilities" can express a real biological fact may well be doubted. Perhaps the basis of heredity is of a very different order from the mechanico-physical conceptions that we habitually apply to it.

Mendel's law of heredity is recently stated as follows by Bateson and Saunders: "The essential part of the discovery is the evidence that the germ-cells or gametes produced by cross-bred organisms may in respect of given characters be of the pure parental types and consequently incapable of transmitting the opposite character; that when such pure similar gametes of opposite sexes are united together in fertilization, the individuals so formed and their posterity are free from all taint of the cross; that there may be, in short, perfect or almost perfect discontinuity between these germs in respect of one of each pair of opposite characters."

This, in barest epitome, is the teaching of Mendel. This teaching strikes at the root of two or three difficult and vital problems. It presents a new conception of the proximate mechanism of heredity, although it does not present a complete hypothesis of heredity since it begins with the gametes after they are formed and does not account for the constitution of the gametes, nor the way in which the parental characters are impressed upon them. This hypothesis will focus our attention along new lines, and I believe will arouse as much discussion as Weismann's hypothesis did; and it is probable that it will have a wider influence. Whether it expresses the actual means of heredity or not it is yet much too early to say; but this hypothesis is a greater contribution to science than the so-called "Mendel law" as to the numerical results of hybridization: the hypothesis attempts to explain the "law."[1]

One great merit of the hypothesis is the fact that its basis is a morphological unit, or at least an appreciable unit, not a mere imaginary concept. This unit should be capable of direct study, at least in some of its phases. It would seem that the Mendelian hypothesis would give a new direction to cytological research.[2]

It is yet too early to say how far Mendel's law applies. We shall need to re-study the work that has been done and to do new work along more definite lines. There are relatively few results of experiments that can be conformed to Mendel's law, because the data are not complete enough or not made from the proper point of view. We should expect the fundamental results to be masked when the plants with which we work are themselves unstable, when cross-fertilization is allowed to take place, or when the pairs of con-

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[1] This, I take it, is also the opinion of Bateson, the leading interpreter of Mendel in English; for he calls his new book on the subject (1902) "Mendel's Principles of Heredity," as if the heredity idea were greater than the hybridization idea.

[2] See, for example, "A Cytological Basis for the Mendelian Laws," Bull. Torr. Bot. Club, 29, 657 (1902), by W. A. Cannon.

trasting characters are very numerous and very complex. Marked numerical results have been found by various workers in different fields, in this country notably by Spillman in hybrid wheats. Mendel was able to discover the numerical law because he eliminated nearly all the confusing contingencies. In the discussion of every bold new hypothesis, we are in danger of becoming partisans, taking a stand either for it or against it. The judicial attitude is also the scientific one. We want to know.

Two processes are now going forward in the discussion of Mendel's law, — one the explaining away of "exceptions," the other the endeavoring to find the true place of the law in the scheme of evolution. The one is primarily an effort to uphold the law; the other is primarily a desire to adjudge it. One is an effort to apply it universally; the other to determine whether it is universal. Already so many adjustments have been made of the Mendelian principles that it is becoming difficult to determine what Mendelism is. These cases are typical of the discussions on almost every vital question connected with evolution. At the hard places we make a supposition and modify the hypothesis in the face of a fact. We can prove anything by supposing.

The results of Mendel's work have two important bearings on current evolution discussion: (1)

on the part that hybridization plays under natural conditions in the evolution of the forms of life, and (2) the part that it plays in plant-breeding. In the former category his work gives a hint of definiteness to the rôle of hybridization in the origination of new combination-forms. In the latter category it is difficult as yet to measure its importance, since extended applications to practice have not been made, and since, also, the Mendelian principles have been themselves so much the subject of debate and definition that it is difficult to distinguish between Mendelism and the endeavor to make the Mendelian suggestions fit our present-day knowledge. In discussing the application of Mendel's work to plant-breeding, I desire to keep in mind the work that he did with peas, upon which the "Mendel law" chiefly rests.

c. *Application to Plant-Breeding.*

The wildest prophecies have been made in respect to the application of Mendel's law to the practice of plant-breeding, for the mathematical formulas express only definiteness and precision. Unfortunately, the formulas cannot express the indefiniteness and the unprecision which even Mendel found in his work. My own feeling is that the greatest benefit of Mendel's work to the plant-breeder will be in improving the methods of experimenting. We can no longer be satisfied with mere "trials" in hybridizing: we must plan the work with great care, have definite ideals, "work to a line," and make accurate and statistical studies of the separate marks or characters of plants. His work suggests what we are to look for.

Beyond this I do not see how the original Mendelian results will greatly modify our plant-breeding practice. The best breeders now breed to unit characters, for this is the significance of such expressions as "avoid breeding for antagonistic characters," "breed for one thing at a time," "know what you want," "have a definite ideal," "keep the variety up to a standard." In certain classes of plants the Mendelian laws will be found to apply with great regularity, and in these we shall be able to know beforehand about what to expect. The number of cases in which the law or some modification of it applies, is being extended daily, both for animals and plants;[1] but in practice we shall probably find as many exceptions to the formulas as confirmations of them, even though the exceptions can be explained, after we find them, by Mendel's principle of heredity.

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[1] See, for example, Bateson and Saunders's report to the Royal Society on heredity. A recent paper by Cuénot (Archives of Exper. and Gen. Zoöl., 1903) gives confirmatory results on hybrid mice, with discussions of the nature of dominance. This line of investigation is likely to be very popular for the next few years.

It has been said that we shall soon be able, as a result of Mendel's discoveries, to predict varieties in plant-breeding. Before considering this question, we must recall the fact that a cultural variety is a succession of plants that has characters sufficiently marked and uniform to make it worth cultivating in place of some older variety. Now and then it may be worth while to introduce some new energy or new trend into a general lot of offspring by making wholesale crosses, not expecting ever to segregate any particular variety or strain from the progeny; but these cases are rare, and the gain is indefinite and temporary. So far as our knowledge at present goes, I see no warrant for the hope that we can predict varieties with any degree of exactness, at least not beyond a very narrow effort. Following are some of the reasons that seem to me to argue against the probability of useful prophecy of varieties so far as the Mendelian results are concerned: (1) We do not know what plants will Mendelize until we try. (2) Even in plants that do Mendelize, only half of the offspring have stable characters. But we cannot predict for even this half, for it is impossible to determine beforehand which seeds showing dominant characters (and these are three-fourths of the offspring) will "come true." Dominance, as we have seen, is of two kinds in respect to its behavior in the next generation, — constant and hybrid; and the hybrid dominance, which is twice as frequent as the other, breaks up into constant dominance, hybrid dominance, and recessiveness. (3) Mendel's law deals primarily with mere characters, not with a variety or with a plant as a whole. Every plant is a composite of a multitude of characters, and from the plant-breeder's point of view there may be as many undesirable characters as desirable ones. No plant is perfect; if it were, there would be no need of plant-breeding. The breeder wants to preserve the desirable characters or traits and eliminate the undesirable ones; but under the strict interpretation of Mendelism this may be difficult and perhaps impossible. The one germ gamete and the one sperm gamete that unite to make the new plant, each contain all the alternative parental characters; these various characters reappear in the offspring, and all that the breeder gains is a new combination or arrangement of characters, and the undesirable attributes may be as troublesome as before. (4) The breeder usually wants wholly new characters as well as re-combinations of old ones, or he wants augmented characters, and these lie outside the true Mendelian categories. For example, a carnation grower wants a four-inch flower, but he has only three-inch flowers to work with, and augmentation of characters is no part of the original Mendelian law. Perhaps these augmented and new characters are to be got by means of ordinary variation and selection, or other extra-crossing means; but we know, as a matter of fact, that augmented characters do sometimes appear in hybrids. (5) New and unpredictable characters are likely to arise from the influence of environment or other causes, and very likely these may be recorded in the gametes and vitiate the final results. (6) Variability itself may be a unit character and therefore pass over. There is probably such a thing as a "tendency to vary," wholly aside from the fact of variation. (7) Many of the plants with which we need most to work in plant-breeding are themselves eminently variable and the results, even if there is true Mendelism, may be so uncertain as to be wholly unpredictable. (8) Many plants with which we must work will not close-fertilize. Some of them are monœcious or diœcious. Even if there is gametic purity in such plants, the probability is that the fact can be discovered only by a long line of scientific experimenting for that particular purpose and not by the work of the man who desires only to breed new plants. (9) A cultural variety, in any true acceptation of the term, is a series of closely related plants having a pedigree. It runs back to one individual plant, from which propagation has been made by seeds or asexual parts. Now, one can never predict just what combination of characters any plant will have, even though it be strictly Mendelian. A person might have a thousand hybrids of which no one plant shows any two characters in the proportion of 3 to 1 (both seed-characters may appear in the same pod or in different pods on the same plant), let alone all the characters as 3 to 1 or in other definite relation; and yet the total average numerical results might conform exactly to the Mendelian law. Mendel's law is a law of averages. The very fact that one must employ such large numbers to secure the numerical results shows that we cannot predict as to individuals. For example, in ten plants of pea, Mendel found the following ratios in respect to seed-shape and seed-color: —

Shape.	Color.	Shape.	Color.
3.75 : 1	2.27 : 1	4.33 : 1	3.33 : 1
3.37 : 1	4.57 : 1	3.66 : 1	2.43 : 1
3.43 : 1	2.80 : 1	2.20 : 1	4.88 : 1
1.90 : 1	2.59 : 1	4.66 : 1	3.57 : 1
2.91 : 1	1.85 : 1	3.57 : 1	2.44 : 1

Mendel reports one instance in which the ratio in seed-shape was 21 to 1, and another of 1 to 1. He also reports instances of seed-color of 32 to 1, and 1 to 1. It has been said that, because of Mendel's work, we shall be able to produce hybrid varieties with the same certainty that we produce chemical compounds. Now, a plant is made up of many combinations of many units, and these combinations are the results of mathematical chance or probability. Of course, when the offspring are numerous, all possible combinations are likely to occur; but these occurrences are essentially fortuitous. Chemical compounds are specific entities in which the parts combine by necessity with definiteness. The comparison, as it appeals to me, is fallacious and the conclusion unsound.

We must remember that there are whole classes of cases of plant-breeding that do not fall under hybridization at all. Granting the De Vriesian view that selection is incompetent to produce species from individual fluctuations, it is nevertheless well established (and admitted by De Vries) that very many of our most useful cultural varieties have been brought to their present state of perfection by means of selection; and by selection they are maintained in their usefulness. Selection will always be a most important agency in the hands of the gardener and the plant-breeder — none the less so now that we have challenged its rôle in the evolution of the plant kingdom. For the time being, the new discussions of hybridization are likely to overshadow all other agencies in plant-breeding; but selection under cultivation is as important now as it was in the days of Van Mons and Darwin.

d. *Interpretation of Hybridism.*

It is probable that the clearest insight into this whole new question of hybridization is to be got by following the work of De Vries. The concluding parts of the second volume of his "Mutationstheorie," a volume devoted wholly to hybridization, is on the press at this moment. The Mendelian laws are fully discussed in this volume, but the summary conclusions may be presented here. De Vries had been working at hybridization long before he discovered Mendel, and had arrived at practically the same results; he had also arrived at other results that are not Mendelian. De Vries denominated the law of numerical segregation as the "law of separation of characters in crosses." Like Mendel, he had found that merely to cross "varieties" or "species" is of no avail in the study of fundamental problems; for the varieties and species that we know are mere systematic groups with characters of all kinds and degrees. We must cross characters or units, not species. [illegible]

Every unit-character De Vries conceives to be represented in the germ by a pangene. This pangene may be active, in which case the character appears in the plant; or it may be dormant, in which case the character is not visible, or for the time being is lost. Active pangenes may at any time become latent, or latent ones may become active.

Mendel's law results from an interchange of contrasting characters. True physiological or elementary species differ from each other by new unit-characters. They have arisen by progressive mutation. The characters are not contrasting or differentiating. One species has one kind of pangene, another species another kind of pangene. On combining these there can be no interchange of characters, and, therefore, no Mendelism. There is nothing for one character to exchange against the other. In the case of true progressive mutations, therefore, upon which the progress of the plant race depends, there can be no Mendelizing. Hybrids in these cases are intermediates, or else follow only one or the other of the parents.

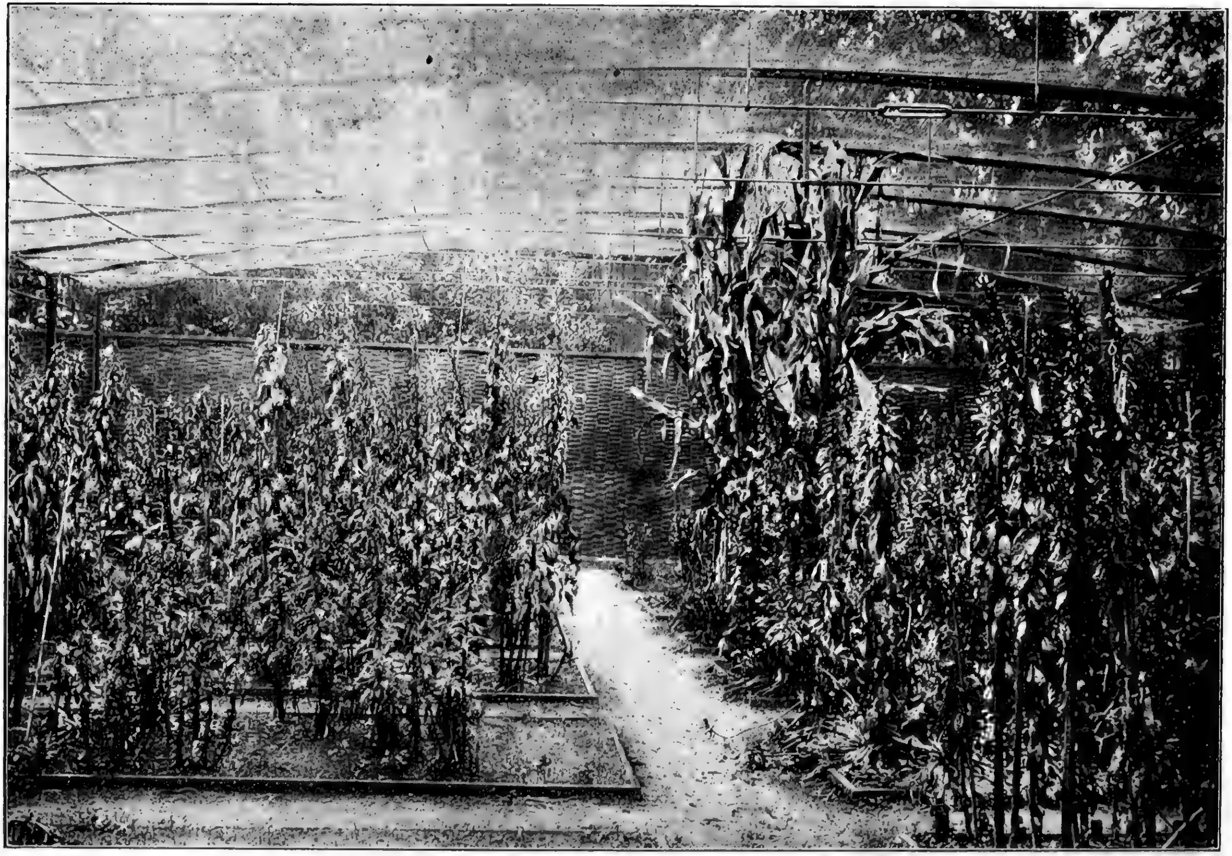
Now, varieties differ from true mutative species in the fact that they have contrasting characters. These characters are represented by their special kinds of pangenes. The pangene may be active or passive. That is, the variety may be a variety because one or more of its characters has become latent (retrogressive), or because characters have become active (degressive). When these characters are crossed, there is an interchange of the pairs. Both parents bear the same unit-character, but this character is active in the one and dormant in the other. The hybrid receives an active pangene from one parent and a similar but inactive pangene from the other. When these two units unite, the calculus of chance determines that there shall reappear in the second generation equal numbers of both the parental units, and a half of the whole that are still hybrids and break up in the same ratio in the third generation. That is, true Mendelism is confined to crossings of retrogressive and degressive varietal characters.

There are, therefore, two general classes of hybrid formation: the isogons, giving rise to crosses in which two antagonistic parental characters reappear in numerical order (Mendelian cases); anisogons, giving rise to crosses in which two antagonistic characters sometimes separate unequally, but ordinarily do not separate at all. When only one parent is represented in the offspring, we have the "unisexual crosses" of Macfarlane or the "false crosses" of Millardet. These are cases in which there are no true contrasting characters. Spillman has recently explained the false hybrids by supposing that the plants in this case are self-fertile and sterile with other pollen. That is, *A* is fertile with *A*, *B* with *B*, but *A* is not fertile with *B* nor *B* with *A*; there results, therefore, no true crossing. This hypothesis should be capable of experimental proof or disproof.

The isogon hybrids are of all degrees of complexity, and classification of them will at once show how far we have already got away from the old systematic idea of variety-hybrids and species-hybrids. Hybrids between plants that differ only in one unit-character are monohybrids. These are the ones in which the numerical results are most clearly traced, but they are also exceedingly rare. Those in which two unit-characters are concerned are dihybrids. In these the combination series gives four different kinds of offspring. So there are trihybrids, giving eight possible combinations, tetrahybrids, and so on to polyhybrids; and in every succeeding grade the difficulties of statistical and comparative studies increase. Of how many characters is a plant composed?

e. *Conclusion.*

Now, in conclusion, what are the great things that we have learned from these newer studies? (1) In the first place, we have been brought to a full stop in respect to our ways of thinking on these evolution subjects. (2) We are compelled to give up forever the taxonomic idea of species as a basis for studying the process of evolution. (3) The experimental method has finally been completely launched and set under way. Laboratory methods, comparative morphology, embryological recapitulation, life-history studies, ecological investigations — all these means are likely to be overshadowed for a time by experiments in actually growing the things under conditions of control. (4) We must study great numbers of individuals



THE CAGE, IN PROFESSOR DE VRIES'S EXPERIMENT GARDEN, SHOWING CORN AND VARIOUS SPECIES OF ŒNOTHERA. BOTANICAL GARDENS, AMSTERDAM.

and employ statistical methods of comparison. (5) The doctrine of discontinuous evolution is now clearly before us. (6) We are beginning to find a pathway through the bewildering maze of hybridization.

Mendelism in Wheat.

In order that I may present a specific example of evident Mendelian results, I have asked W. J. Spillman, agriculturist of the Department of Agriculture, to explain some of his experiments with wheat.[1] Mr. Spillman independently discovered numerical results, before the knowledge of the Mendelian experiments had become generally known.

"The photograph (p. 183) shows three generations of one of my hybrid wheats. Of the three heads in the upper row, the left-hand one is the male parent (variety Valley); the right-hand one is the female parent (variety Little Club); and the middle one is the hybrid. The second row shows the second generation, and the third row the third generation. Of the six types in the second generation, the following points are important: Each type was present in a certain proportion, which was approximately the same as in thirteen other similar cases, and the average of these fourteen cases closely approximated the theoretical numbers

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[1] For illustration in maize, see p. 227.

called for by Mendel's hypothesis of the disjunction of parental characters. The three at the left, being bearded, possess a character which was latent in the first generation. The fact that the beards show in these three indicates that the opposite character is absent, and they should therefore remain bearded in succeeding generations. That is, they are no longer hybrid with reference to this character. It will be observed that this was actually the case, for no beardless heads appeared in the progeny of either of these three (see lower row, first five heads). The following diagram will show the character of each of the six types in row two. In this diagram the letters have the following meanings: —

B = bearded (written *b* when latent).
S = smooth (not bearded).
L = long heads.
C = club heads (short).
I = intermediate in length of head. (The hybrid was intermediate in this respect.)

Parents.	First Generation.	Second Generation.
		1 *BL*
		2 *BI*
BL		1 *BC*
		2 *SbL*
	SbI	4 *SbI*
		2 *SbC*
		1 *SL*
SC		2 *SI*
		1 *SC*
		16

THREE GENERATIONS OF HYBRID WHEAT.

A 1 = male parent, A 2 = the hybrid, A 3 = female parent. B 1–6 = the progeny of A 2. C 1 = progeny of B 1. C 2–4 = progeny of B 2. C 5 = progeny of B 3. C 6 and 7 = progeny of B 4. C 8–13 = progeny of B 5. C 14 and 15 = progeny of B 6. The results in the fourth generation, available too late to include in the photograph, indicate that B 2 and B 3, while not always separable on external appearances, are absolutely different, the one being hybrid, the other pure.

"This diagram shows the nine types called for by Mendel's theory. Of these, *BL*, *BC*, *SL*, and *SC* are no longer hybrids — at least they have no latent characters, and will therefore reproduce true to seed. Of the remaining five types, *BI* and *SI* are hybrid only with reference to length of head, and *SbL* and *SbC* only with reference to beards; while *SbI* is hybrid with reference to both characters, as in the preceding generation.

"It will readily be seen that the types *BL* and *BC* can be separated from the other seven by external appearances, and obtained in a pure state. *BL* is the type shown at the left in the second row in the picture, and all its progeny was like it, showing that it conformed to theory. *BC* is the type shown at No. 3 in the second row of heads; being pure, it should reproduce itself true to type, which it did, with an easily explained exception to be noted below. The type *BI* (shown at No. 2, row 2) being hybrid with reference to length of head, should produce again all the types based on this character, and it did this as is seen in heads 2–4, row 3. Referring again to the above diagram, it will be seen that the types *SL* and *SbL* cannot be distinguished by external characters. *SL* will of course reproduce true to type, while *SbL* will produce *SL*, *SbL*, and *BL*. Now *SL* and *SbL* being mixed together in the selection made in the second generation, we should find a large percentage of *SL* mixed with some *SbL* from which it cannot be distinguished, and a small percentage of *BL* in the third generation. Heads 6 and 7, row 3, show that the types called for actually occurred. Types *SI* and *SbI* of the diagram appear alike externally, and were therefore selected together in the second generation (see head 5, row 2). Now *SI* should produce the types *SL*, *SI*, and *SC*, while *SbI* should produce all nine types again (these nine types can be separated only into six by external appearance). It is therefore seen that the group represented by head 5, row 2, should produce all six types again. Heads 8–13, row 3, show these types. Types *SbC* and *SC* of the diagram are alike externally, and were hence selected together last year. Of these *SC* should produce only *SC*, while *SbC* should produce *SC*, *SbC*, and *BC*. But since *SC* and *SbC* look alike, the progeny of these two types should show only *SC* and *BC*. The last two heads in row 3 show that this actually occurred.

"In the single set of heads shown, there were two easily explained exceptions to theory. It will be seen that heads 2 and 3, row 2, differ only in length; now the group represented by head 2 varied in length from that of 1 to that of 3. In separating 2 and 3, it might easily happen that some of 3 should be placed with two. In this case the progeny of 3 would show a few heads like 1, and this was the case. I have shown in the photograph only the heads called for by theory, for it would only lead to confusion to include the exceptions which would probably not have occurred if 2 and 3 of row 2 had been accurately separated last year. Again, in the progeny of the group represented by head 5, row 2, only five of the six types shown (row 3, heads 8–13) were found in this particular case, though all six were found in most of the others. As the missing type should constitute only $4\frac{1}{6}$ per cent of the group, and as it differed from one of the others only slightly, it is possible that it was included with the related type when the selections were made.

"I have not yet seen the data for the third generation of all these wheats, but those which are at hand are decidedly interesting.[1] The following are the data for the third generation of the cross between Jones Winter Fife (male) and Little Club (female). The Fife is long-headed, and has velvet chaff (V); the Club short-headed, and has glabrous chaff (G). Velvet proved to be dominant over glabrous, and the hybrids were intermediate in length. Type I. of the second generation included the two types VL and VgL, since these could not be distinguished by external appearances. Seed of Type I. produced in the third generation: —

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[1] Data for the fourth generation, now at hand, agree well with the theory.

Plot.	Percentage of Types.	
	I. = *VL*.	II. = *GL*.
1	87	13
2	81	19
Theory	$83\frac{1}{3}$	$16\frac{2}{3}$

The figures for the remaining five second-generation types are as follows: —

Type II. = *GL*.

Plot.	Percentage of Types. II.
1	100
2	100
Theory	100

Type III. = *VI* and *VgI*.

Plot.	I.	II.	III.	IV.	V.	VI.
1	21	7	38	9	20	5
2	19	$4\frac{1}{2}$	38	12	15	$4\frac{1}{2}$
Theory	$20\frac{5}{6}$	$4\frac{1}{6}$	$41\frac{2}{3}$	$8\frac{1}{3}$	$20\frac{5}{6}$	$4\frac{1}{6}$

Type IV. = *GI*.

Plot.	II.	IV.	VI.
1	28	52	20
2	31	47	22
Theory	25	50	25

Type V. = *VC* and *VgC*.

Plot.	I.	II.	V.	VI.
1	2.4		80.0	17.6
2	4.7	2.6	79.8	12.9
Theory			$83\frac{1}{3}$	$16\frac{2}{3}$

Type VI. = *GC*.

Plot.	II.	VI.
1	7.7	92.3
2	—	100.0
Theory		100.

"The only departures from theory of any consequence in these data are the occurrence of small amounts of Types I. and II. in the progeny of V., and of II. in the progeny of VI. Now, Type V. of the second generation (*VC* and *VgC*) differed from Type III. (*VI*) only in being slightly shorter. If a few individuals of III. had been included in V. in separating the types of the second generation, we should have the actual result obtained in the third generation. Likewise, Type VI. of the second generation (*GC*) differed from II. (*GI*) in the same manner. Evidently a few plants of II. got into the Type VI. last year, and thus gave the results shown.

"These hybrids are now under the care of Professor E. E. Elliott, of Pullman, Washington; and from a recent letter I infer that spring character in wheats is dominant over the winter character, as a large majority of the fourth generation have the spring character (all the club wheats used were spring wheats).

"The original purpose of this work was to produce a winter-club wheat, a type much needed in eastern Washington. It is probable that the effort was successful, but the invariable interruptions to work that follow a change of personnel in the workers has delayed the final results.

"It now seems probable that Mendel's theory is true, at least in these wheats. If this theory should prove generally true, the following most important fact follows: If the individuals of the second generation are numerous enough, there is present in this generation every possible combination of the parent characters, and, most important of all, every one of these combinations is present in some individuals in a fixed form that will reproduce true to seed. The fixed forms can easily be separated from the others by treating each plant of the second generation as an individual, and noting which of them reproduce true to seed.

"It should further be noted that the forms not already fixed in the second year will, in later generations, gradually break up into the same fixed forms as those occurring in the second generation. It is therefore possible to secure in the third generation all the pure fixed forms that can be secured from a hybrid. (Close fertilization is assumed in all cases.)"

II. On Hybridization.

By Hugo De Vries.

(Written expressly for the third edition of "Plant-Breeding.")

Hybrids are ordinarily said to be intermediate between their parents. But by a closer inspection this relation appears to be of a complex nature; for the intermediate state may be such in regard to the single characters, or may be the result of the mixing of pure or nearly pure paternal and maternal characters in the same individual. Generally it is said that specific characters are handed over in a more or less reduced degree, but that racial peculiarities take either to the father or to the mother.

The difference between specific and racial marks is of course as much a question of personal appreciation as is the limit between species and races or varieties itself. But it is clear that the behavior of hybrids, both natural and artificial, does not depend upon our appreciation of the facts, but on the facts themselves. We have therefore to search for a character which is independent of the systematic value given to the groups in question.

Such a criterion is yielded by the theory of the origin of species by mutations. Of course the theory only indicates the principle, and much work will have to be done before it will be possible to apply it in all individual cases. But a clear conception of the ruling idea will point to the direction in which the experiments will have to be made, and it will assist the hybridist in a more thorough comparison of the hybrids and their parents. Moreover, a consideration of the characters of the parents from the new point of view will enable him, in the majority of cases, to foretell, with a greater or lesser degree of preci sion, the characters which may be expected to make their appearance in a new hybrid.

The theory of mutation assumes that the qualities of a plant are not the expressions of a single, so-called "specific character," but depend on different units. These units are more or less independent of one another, and may be combined in different ways. Two or more allied species might consist of absolutely the same characters, but in different combinations.

According to this view the progress in living nature has been by steps. Each step contributes a new character to those already existing, adding one unit more to the stock. It is evident that of all the species of a genus, the nearest ally of any given one is that from which it has taken its origin. This origin is assumed to have taken place by shocks or leaps; or if the idea of a leap should confer the notion of too great a difference, one might use the expression, "by steps." In horticulture such steps are often called sports; but the meaning of this word comprises so many notions, and is so often limited to bud-sports, which mostly are of another nature, that I prefer to avoid it.

Each leap or step signifies the acquisition of a single new character; and elementary species must therefore differ from their nearest allies only in the possession of a single one. As a matter of fact, the difference between the species of one genus are often not only greater, but even very much greater. But this is accounted for by the extinction of a greater or lesser number of forms, which no doubt is and has been of very general occurrence and must of course break up the continuity in the series of the remaining types. In such groups as *Draba verna*, *Helianthemum vulgare*, *Viola tricolor*, the hieraciums, roses, brambles, and many other so-called younger genera and species, the single forms are so nearly allied that it is very difficult or perhaps even impossible to distinguish them from one another. These are the types of the original arrangement which is to be assumed for all groups consisting at present of more widely different forms, and, as is commonly said, now showing "gaps."

Such small steps are called mutations, and more particularly progressive mutations, because they contribute to the evolution of the group. Once obtained, a new character may remain constant for centuries, and the new species will show no progress till a further mutation takes place and changes it again into a new specific form. The whole evolution goes on by such steps, the periods between the successive bounds showing no signs of progress, but leaving the species unchanged. In this way it is clear that constancy of species and mutual descendance are in perfect harmony with one another.

Besides the progressive mutations, there are other changes which are of minor value for the evolution in general, but of more general interest to horticulture. First of all, a character, once obtained, may be visible in the plant or it may become invisible, inactive, or as it is ordinarily called, dormant or latent. For instance, the blue and red colors of many flowers may disappear and thereby give rise to the white-flowered varieties. The visible quality is lost in such cases, but the corresponding internal one is not really lost, but has only become inactive or sleeping. That this is the case is seen in the frequent reversions in general, and particularly in the numerous instances of reversion by bud-variation as shown by variegated trees and shrubs, and by quite a host of garden varieties of evergreens (*e.g. Cephalotaxus pedunculata* var. *fastigiata*, *Cryptomeria Japonica* var. *spiraliter falcata*, etc.).

If now we compare a species with its mother-species, and a variety with its species, we readily see the difference. In both cases the difference in the description is caused by but a single character. But in the first case the internal character of the germ is present in the one and wanting in the other, whilst in the second case it is present in both and only different as to the degree of its activity, being active in the one and latent in the other.

From this comparison we at once see that the behavior of two plants, when sexually united with one another, must differ principally in the two instances above mentioned. All other characters are assumed to be the same in both parents, and their union must follow the common rule of fertilization. But we must expect to get a different hybrid if the diagnostic character present in the elder one of the two forms is wanting in the younger one or is present but inactive. The active and the latent character may be simply interchanged, but in the case of a progressive mutation an exchange of characters is of course impossible.

Activity and latency are not the sole degrees of development of a character. Nor is the difference between two forms, used for a crossing, ordinarily limited to a single point. But for the sake of clearness it seems better first to discuss these more simple cases and to put off the more complicated ones till after having elucidated the former.

The becoming dormant of a character is one of the most ordinary types of the production of varieties. It is to be regarded as a mutation, since it is known in horticulture to come about by leaps and bounds. In the outer features it sets back the evolution as much as it had been brought forward by the progressive mutation by which the character in question was first obtained. For this reason the seeming loss may be called a retrogressive mutation.

Limiting ourselves provisionally to these two types of differences between the two plants chosen for a crossing experiment, we will, for brevity's sake, call "species" two forms of which the one has been derived from the other by a progressive mutation, and "variety," the form derived from another in the way of retrogressive mutation. In this way we come to a very simple statement of the internal phenomena of crosses in general. For, in the first case, one parent has a character which is lacking in the other, and no exchange is possible. In the second case, both parents bear the same character, active in one, dormant in the other, and here they may therefore simply be exchanged.

This exchange is governed by the laws of probability and depends, as far as we know, on no other principle or general laws. The application of the laws of probability to this process was first discovered by Mendel, and the laws of exchange of characters in hybrids are now generally known as the laws of Mendel. They are limited to the crossing of varieties.

If no exchange is possible because the differential character is wholly wanting in the other parent, we may call the union "unisexual," as was first proposed by Macfarlane. The extant features are then handed down to the hybrid offspring, but in a reduced state. Ordinarily they are reduced to one-half, as Macfarlane has pointed out; but this is only a mean, around which the single cases seem to be grouped in the ordinary manner, most of them more or less strictly observing the rule, others differing in varying degrees. In extreme cases such variation can go so far as to repeat the character in question in the hybrid, or, on the other hand, to cause it to be wholly wanting. Hybrids from such unisexual crosses are ordinarily constant in their progeny, repeating in each successive generation the characters of the first one. Such races do not obviously differ from true species, and Kerner has shown that in many cases wild species may owe their origin to such a cross. But instances are as yet rare, because, ordinarily, the two plants chosen for a cross differ in more than one point, and even mostly differ partly in specific characters, and partly in such as have been obtained by retrogressive mutations.

Hybrids of varieties follow Mendel's laws, as we have said. Two essential points are here to be distinguished, viz., the character invisible in the hybrid itself, and the behavior of the two opposite qualities in their progeny. We will first consider the hybrids themselves.

According to the limits chosen above for our present discussion, the hybrid inherits from one parent a character in an active condition, and from the other the same character in a dormant state. From this method of viewing their constitution, it is evidently to be expected that the differential character will be active in the hybrid too, perhaps aided but perhaps also more or less hindered in its expression by the dormant counterpart. The evidence afforded by the experiments of Mendel, Correns, Tschermak, Webber, and myself shows that the differential character is really active in the hybrids, and that the weakening by its dormant opponent is ordinarily very slight, often wholly wanting, and only occasionally reducing it to nearly one-half. (*Hyoscyamus pallidus* × *niger.*) This rule is commonly expressed by saying that the phylogenetically older character, *i.e.* that of the species, is dominant or prevailing over the antagonistic character of the younger parent or the variety. It is the first of Mendel's laws, but here expressed in terms, not of Mendel, but proper to the mutation theory.

The second of Mendel's laws governs the splitting up of the character in the offspring of the hybrids. Mendel assumes that at the time of the production of the sexual cells the two antagonistic qualities, combined in the hybrid, separate and leave each other, the dominant coming into one-half of the male and female elements, and the opposite or recessive coming into the other half.

If now, in the act of fertilization, the male and female cells are combined simply according to the laws of probability, each cell has an equal chance to unite with a cell bearing the same or with a cell bearing the opposite character. This leads to four combinations of equal frequency, a male dominant combining with a dominant or a recessive female, and a male recessive uniting in the same way with a dominant or a recessive female. Or, having no regard to the sex, we have dominant × dominant, recessive × recessive, and two cases of dominant × recessive.

The offspring of hybrids consists, therefore, of three different groups of individuals. One of them bears only the active character, one of them only the latent, and the other group, containing the double number of specimens of each of the two first, consists of new hybrids. The first group will have the character of one grandparent, the second that of the other, the third that of the parents or hybrids of the first generation. The two first divisions will be constant like the original parent-species; the last one must split up in the same way as the original hybrids themselves. No new form is obtained by such a crossing, as no new combination of qualities was possible. The hybrids obtained are called monohybrids, because the parents differ only in a single point. They are evidently of no practical interest, but it is equally evident that they give us the key to the explanation of the phenomena exhibited in the more complex cases; for, as a rule, these obey the same laws as the monohybrids with respect to the different distinguishing characters, whilst these are themselves combined according to the ordinary laws of probability.

If we sexually combine two forms, which differ in two points, the hybrids are called dihybrids; if the difference extends to three or more characters, they bear the names of tripolyhybrids. The most important result of the study of such cases is, that the different characters of the parents may be united by crossing and give rise to hybrids, of which some are constant in their progeny and others not. The last ones split up according to the same rules as do the monohybrids, and are only of theoretical interest or at best are the means of obtaining the constant races in an easier, though slower, way than by getting them directly. On the other hand, the constant races are of the highest value, as well in horticultural as in agricultural practice. As many combinations as are to be expected really appear as constant races. If the crossed varieties differ in two characters, two new combinations are possible and obtained. For instance, by crossing the blue and thorny thorn-apple with the white-flowered thornless variety, one obtains blue thornless and white thorny forms, each of which gives a constant race. In the case of three differential characters, eight combinations are possible, two of them are equal to the parents, and so we will expect six new races, as, for instance, in the cases of wheat and oats studied by Rimpau (cf. "Mutationstheorie," II., p. 192). The practical horticulturists and agriculturists will have to choose from these new races the best ones for further cultivation, but the numerical laws of Mendel will enable them to calculate beforehand what they have to expect and in which way they have to direct their selections.

The laws of Mendel are not only valid for the cases of retrogressive variations, they also may be applied to all other cases, in which the differential character is internally present in both parents of a cross, but in different conditions. The principal conditions are the active and the dormant ones, constituting, as we have seen, the species and the constant variety. But there are other conditions of which we have here to name only the semi-active one. This is the internal character of those extremely variable forms which are so highly esteemed in horticulture, as double flowers, variegated leaves, and so on. Crossed with the true species, they comply with Mendel's laws, and the results of the crossings, therefore, may be calculated beforehand. But their high degree of variability is inherited by the hybrids and makes it often very difficult as well to prove this compliance as to make use of it in practice.

Coming now to even more complicated cases, we have to treat of those in which some characters differ progressively or unisexually and others in the retrogressive or in the digressive way. Or, in other terms, we have to inquire into the crossings in which the parents differ at once in specific and in varietal or racial marks. It will be readily seen that this case, though very complicated from an analytical point of view, is in practice the ordinary one. Pure unisexual or pure Mendel crosses are very rare, and seldom of great importance. Nearly all interesting horticultural crossings bear the mixed character we now have to speak of. The mutation-theory of course assumes the reciprocal independence of the single characters for this case also. The unisexual differences must follow the laws studied by Macfarlane, the antagonistic qualities those pointed out by Mendel. In regard to the first, the hybrids will therefore be in some degree intermediate between the parents, and constant in their progeny. In regard to the last, they will bear the dominant characters, and split up in their children, giving as many new constant strains as new combinations of these characters are possible.

It is evident that the applications of the laws above mentioned may in this manner lead to the calculating beforehand of the results of all projected crosses. But the researches are as yet only in their prime, and the true distinction of the units of the characters, which has to be the base of all such calculations, demands much previous experimental work.

The discussions given above concern only species and varieties in the ordinary immutable state. When mutable, the conditions of the internal characters are of course totally different, and neither the laws of the unisexual crossings nor those of Mendel are applicable. (See De Vries's paper "On Crosses with Dissimilar Heredity.")

III. THE FORWARD MOVEMENT IN PLANT-BREEDING.[1]

The first specific interest in cultivated plants was in the gross kinds or species. As the contact with plants became more intimate, various indefinite form-groups were recognized within the limits of the species. Gradually, with the intensifying of domestication and cultivation, very particular groups appeared and were recognized. These smaller groups came finally to be designated

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[1] Read April 2, 1903, before the American Philosophical Society, and reprinted, with minor alterations, from proceedings of the society, Vol. XLII. No. 172.

by names, and the idea of the definite and homogeneous cultural variety came into existence. The variety-conception is really a late one in the development of the human race. It is practically only within the past two centuries that cultivated varieties of plants have been recognized as being worthy of receiving designative names. It is within this period, also, that most of the great breeds of animals have been defined and separately named.

All this measures the increasing intimacy of our contact with domesticated plants and animals. It is a record of our progress. The peoples that are most advanced in the cultivation of any plant are the ones that have the most named varieties of that plant. In Japan, to this day, the plums are said to pass under ill-defined class names. We have introduced these classes, have sorted out the particular forms that promise to be of value to us, and have given them specific American names. Not long ago a native professor in Japan wrote me asking for cions of these plums, in order that he might introduce Japanese plums into Japan. The Russian apples are designated to some extent by class-names; in fact, it was not until the appearance of Regel's work, about a generation ago, that Russian pomology may be said to have been born. What constitutes a variety is increasingly more difficult to define, because we are constantly differentiating on smaller points. The growth of the variety-conception is really the growth of the power of analysis.

The earlier recognized varieties seem to have come into existence unchallenged. There is very little record of inquiry as to how or why or even where they originated. That is, the quest of the origin arose long after the recognition of the variety as a variety. Even after inquisitive search into origins had begun there was little effort to produce these varieties. The describing of varieties and the search into their histories was a special work of the nineteenth century. One has only to consult such American works as Downing's "Fruits and Fruit Trees of America," and Burr's "Field and Garden Vegetables of America," to see how carefully and methodically the descriptions and synonymy of the varieties were worked out. These are types of excellent pieces of editorial and formal systematic work.

There have been isolated efforts at producing varieties for many years. These efforts began before the time of the general discussion of organic evolution. In fact, it was on such experiments that Darwin drew heavily in some of his most important writing. Roughly speaking, however, the conception that the kinds of plants can be definitely modified and varied by man is a product of the last half century. We now believe that there is such a possibility as plant-breeding. It is really a more modern conception, so far as its general acceptance is concerned, than animal-breeding. But both animal-breeding and plant-breeding are the results of a new attitude toward the forms of life — a conviction that the very structure, habits, and attributes are amenable to change and control by man. This is really one of the great new attitudes of the modern world.

Formerly, and even up to the present time, the variety has been taken as the unit for plant-breeding work, as it has been for descriptive and classificatory work. Whether we believed it or not, we have accepted it as a fairly definite thing or entity. Yet, what is a variety? Only the ideal of one man or a set of men. Custom may define its boundaries, but in fact it has no boundaries. At best, a variety is only an assemblage of forms that agree rather more than they differ; and any one of these forms may, with equal propriety, be called another variety. Shall we continue to consider the variety as a unit or basis from which we are to breed for the purpose of producing other varieties? Or shall we still further refine our ideals, and find that the variety-conception is really only a mark of an imperfect and superficial expression of an immature age?

Now, plant-breeding is worthy of the name only as it sets definite ideals and is able to attain them.

Merely to produce new things is of no merit: that was done long before man was evolved. A child can "produce" a new variety, but it may learn nothing and contribute nothing in producing it. I have myself produced fifteen hundred new kinds of pumpkins and squashes, but I had no idea what I was to produce, the world is no better for my having produced them, and I am no wiser (except in experience) than I was before. In many "new" things that are produced there may be dispute as to whether they are new, and as to whether they are distinct enough to be named and therefore to be ranked as varieties at all. This is not science, nor even breeding: it is playing and guessing. What does the world care whether John Jones produces "Jones's Giant Beardless Wheat"? But it does care if he produces a wheat having a half of one per cent more protein. We must give up the production of mere "varieties"; we must breed for certain definite attributes that will make the new generations of plants more efficient for certain purposes: this is the new outlook in plant-breeding.

Happily, we are not without abundant accomplishment in this new field. The last ten years has seen a remarkable specialization in the producing of plants that are adapted to particular needs. The days of merely crossing and sowing the seeds to see what will turn up are already past with those who are engaged seriously in the work. The old method was hit-and-miss, and the result was to take what good luck put in our way: the new method proceeds definitely and directly, and the result is the necessary outcome of the line of effort. The crux of the new ideal is efficiency in one particular attribute in the product of the breeding. These attributes are measurable; the kind of results are foreseen in the plan, or are predictable.

All these remarks are typically illustrated in many investigations now making in the experiment stations. As an example, I will describe the experiments with corn-breeding now conducting in Illinois. It is significant to note what are the reasons for breeding new corns, as stated by Professor Hopkins in Bulletin 82 of the Illinois Experiment Station.

"In its own publication a large commercial concern, which uses enormous quantities of corn, makes the following statements: —

"'A bushel of ordinary corn, weighing fifty-six pounds, contains about four and one-half pounds of germ, thirty-six pounds of dry starch, seven pounds of gluten, and five pounds of bran or hull, the balance in weight being made up of water, soluble matter, etc. The value of the germ lies in the fact that it contains over forty per cent of corn oil, worth, say, five cents per pound, while the starch is worth one and one-half cents, the gluten one cent, and the hull about one-half cent per pound.

"'It can readily be seen that a variety of corn containing, say, one pound more oil per bushel would be in large demand.

"'Farmers throughout the country do well to communicate with their respective agricultural experiment stations and secure their coöperation along these lines.'

"These are statements and suggestions which should, and do, attract the attention of experiment station men. They are made by the Glucose Sugar Refining Company of Chicago, a company which purchases and uses, in its six factories, about fifty million bushels of corn annually. According to these statements, if the oil of corn could be increased one pound per bushel, the actual value of the corn for glucose factories would be increased five cents per bushel; and the president of the Glucose Sugar Refining Company has personally assured the writer that his company would be glad to pay a higher price for high oil corn whenever it can be furnished in large quantities. The increase of five cents per bushel on fifty million bushels would add $2,500,000 to the value of the corn purchased by this one company each year. The glucose factories are now extracting the oil from all the corn they use and are unable to supply the market demand for corn oil. On the other hand, to these manufacturers protein is a cheap by-product, and consequently they want less protein in corn.

"Corn with a lower oil content is desired as a feed for bacon hogs, especially for our export trade, very extensive and thorough investigations conducted in Germany and Canada having proved conclusively that ordinary corn contains too much oil for the production of the hard, firm bacon which is demanded in the markets of Great Britain and Continental Europe."

It is very interesting to note that this does not mention the improvement of Leaming's White, or Jones's Yellow Dent, or any other named variety of corn, nor does it propose that any new variety shall be created. It suggests what may be done with any variety of corn. The experiments in Illinois demonstrate that "the yield of corn can be increased, and the chemical composition of the kernel can be changed as may be desired, either to increase or decrease the protein, the oil, or the starch."

The breeding of the corn, in the Illinois experiments, proceeds along two general lines, — for physical perfection and for chemical perfection. Selection for physical merit proceeds as follows, to quote again from Professor Hopkins: "The most perfect ears obtainable of the variety of corn which it is desired to breed should be selected. These ears should conform to the desirable standards of this variety, and should possess the principal properties which belong to perfect ears of corn, so far as they are known and as completely as it is possible to secure them. These physical characteristics and properties include the length, circumference, and shape of the ear and of the cob; the number of rows of kernels and the number of kernels in the row; the weight and color of the grain and of the cob; and the size and shape of the kernels. In making this selection the breeder may have in his mind a perfect ear of corn and make the physical selection of seed ears by simple inspection, or he may make absolute counts and measurements and reduce the physical selection almost to an exact or mathematical basis."

The selection for chemical content is made on two bases, — on the general gross structure of the corn kernel as determined by "mechanical examination," and on chemical analysis of the kernel.

Chemical examination by means of mechanical examination is as follows: "The selection of seed ears for improved chemical composition by mechanical examination of the kernels is not only of much assistance to the chemist in enabling him to reduce greatly the chemical work involved in seed-corn selection, but it is of the greatest practical value to the ordinary seed-corn grower who is trying to improve his seed corn with very limited service, if any, from the analytical chemist. This chemical selection of seed ears by mechanical examination, as well as by chemical analysis (which is described below), is based upon two facts: —

"1. That the ear of corn is approximately uniform throughout in the chemical composition of its kernels.

"2. That there is a wide variation in the chemical composition of different ears, even of the same variety of corn. These two facts are well illustrated in the table: —

PROTEIN IN SINGLE KERNELS.

	EAR A, PROTEIN, PER CENT.	EAR B, PROTEIN, PER CENT.	EAR C, PROTEIN, PER CENT.	EAR D, PROTEIN, PER CENT.
Kernel No. 1	12.46	11.53	7.45	8.72
Kernel No. 2	12.54	12.32	7.54	8.41
Kernel No. 3	12.44	12.19	7.69	8.73
Kernel No. 4	12.50	12.54	7.47	8.31
Kernel No. 5	12.30	12.14	7.74	8.02
Kernel No. 6	12.49	12.95	8.70	8.76
Kernel No. 7	12.50	12.84	8.46	8.89
Kernel No. 8	12.14	——	8.69	9.02
Kernel No. 9	12.14	12.04	8.86	8.96
Kernel No. 10	12.71	12.75	8.10	8.89

"It will be observed that while there are, of course, small differences among the different kernels of the same ear, yet each ear has an individuality as a whole, the difference in composition between different ears being much more marked than between different kernels of the same ear.

"The uniformity of the individual ear makes it possible to estimate or to determine the composition of the corn by the examination or analysis of a few kernels. The remainder of the kernels on the ear may then be planted if desired. The wide variation in the composition between different ears furnishes a starting-point for the selection of seed in any of the several different lines of desired improvement.

"The method of making a chemical selection of ears of seed corn by a simple mechanical examination of the kernels is based upon the fact that the kernel of corn is not homogeneous in structure, but consists of several distinct and readily observable parts of markedly different chemical composition. Aside from the hull which surrounds the kernel there are three principal parts in a grain of corn: —

"1. The darker colored and rather hard and horny layer lying next to the hull, principally in the edges and toward the tip end of the kernel, where it is about three millimetres, or one-eighth of an inch in thickness.

"2. The white, starchy-appearing part occupying the crown end of the kernel and usually also immediately surrounding, or partially surrounding, the germ.

"3. The germ itself, which occupies the central part of the kernel toward the tip end.

"These different parts of the corn kernel can be readily recognized by merely dissecting a single kernel with a pocket-knife, and it may be added that this is the only instrument needed by anybody in making a chemical selection of seed corn by mechanical examination.

"The horny layer, which usually constitutes about sixty-five per cent of the corn kernel, contains a large proportion of the total protein in the kernel.

"The white, starchy part constitutes about twenty per cent of the whole kernel, and contains a small proportion of the total protein. The germ constitutes only about ten per cent of the corn kernel; but while it is rich in protein, it also contains more than eighty-five per cent of the total oil content of the whole kernel, the remainder of the oil being distributed in all of the other parts. . . .

"By keeping in mind that the horny layer is large in proportion, and also quite rich in protein, and that the germ, although rather small in proportion, is very rich in protein, so that these two parts contain a very large proportion of the total protein in the corn kernel, it will be readily seen that by selecting ears whose kernels contain more than the average proportion of germ and horny layer, we are really selecting ears which are above the average in their protein content. As a matter of fact, the method is even more simple than this, because the white, starchy part is approximately the complement of, and varies inversely as, the sum of the other constituents; and to pick out seed corn of high protein content it is only necessary to select those ears whose kernels show a relatively small proportion of the white, starchy part surrounding the germ.

"As more than eighty-five per cent of the oil in the kernel is contained in the germ, it follows that ears of corn are relatively high or low in their oil content, according as their kernels have a larger or smaller proportion of germ.

"In selecting seed corn by chemical analysis, we remove from the individual ear two adjacent rows of kernels as a representative sample. This sample is ground and analyzed as completely as may be necessary to enable us to decide whether the ear is suitable for seed for the particular kind of corn which it is desired to breed. Dry matter is always determined in order to reduce all other determinations to the strictly uniform and comparable water-free basis. If, for example, we desire to change only the protein content, then protein is determined. If we are breeding to change both the protein and the oil, then determinations of both of these con tituents must be made."

Any careful farmer can make such examinations as these. The relative abundance of one or the other of three areas in the kernel will indicate what ears should be chosen for seed. Professor Hopkins proposes a system of field trials in which one ear furnishes plants for one row, thereby allowing the operator to see and measure the individuality of each ear. By choosing ears that most nearly approach the ideal, and then by continued selection, the desired result is to be secured.

It is impossible to overestimate the value of any concerted corn-breeding work of this general type. The grain alone of the corn crop is worth about one billion dollars annually. It is no doubt possible greatly to increase this efficiency.

An interesting cognate inquiry to this direct breeding work is the study of the commercial grades of grains. It is a most singular fact that the dealer's "grades" are of a very different kind from the farmer's "varieties." In the great markets, for example, corn is sold as "No. 1 Yellow," "No. 2 Yellow," "No. 3 Yellow." Any yellow corn may be thrown into these grades. What constitutes a grade is essentially a judgment on the part of every dealer. There is, therefore, a very natural tendency on the part of dealers to deliver grain as near the bottom of the grade line as an inspector will pass, and consequently there is a marked deterioration as the grain reaches the seaboard. The result is that the grain is likely to be condemned or criticised when it reaches Liverpool. Complaints having come to the government, the United States Department of Agriculture has undertaken to determine how far the grades of grain can be reduced to indisputable instrumental measurement. This work is now in the hands of C. S. Scofield, in the Bureau of Plant Industry. The result is likely to be a closer defining of what a grade is; and this point once determined, the producer will make an effort to grow such grain as will grade to No. 1, and thereby reach the extra price. Eventually the efficiency points of the grower and the commercial grades of the dealer ought nearly or quite to coincide. There should come a time when corn is sold on its inherent merits, as, for example, on its starch content. This corn would not then be graded 1, 2, and 3 on its starch content, because that content would be assured in the entire product; but the Grade 1 would mean prime physical condition, and the lower grades inferior physical condition. Eventually something like varietal names may be attached to those kinds of corns that, for example, grade fifteen per cent protein. The name would be a guarantee of the approximate content, as it now is in a commercial fertilizer.

Closely allied to the corn-breeding work of Illinois (which is carried on by the Experiment Station and also by a commercial firm) is the wheat-breeding and flax-breeding work in Minnesota under the direction of Professor Hays. Mr. Hays's aim has been chiefly to increase general value per acre. The following sketch is made from his notes:—

Examples are given of increased efficiency in varieties produced at the Minnesota Experiment Station in coöperation with the U. S. Bureau of Plant Industry and other stations.

Minn. No. 163 wheat was bred by selection from Fife parentage. During three years' comparison in field tests at University Farm, near Minneapolis, it averaged 2.7 bushels gain per acre, or eleven per cent better than its parent variety, as shown by the following table:—

Minn. No. 163	28.5	bushels
Fife parent	25.8	"
Increase	2.7	"

In 1899, this wheat was sold to one hundred farmers, thirty-eight of whom made the comparison between this and their common wheats in a manner fair to both. The following table shows the average increased yield to have been 1.4 bushels per acre, or eight per cent:—

Minn. No. 163, average yield	18.1	bushels
Common wheats, average yield	16.7	"
Increase	1.4	"

In 1903, this wheat grew on at least 100,000 acres, and since it was first distributed it has produced $100,000 more than would have resulted from the varieties that it has displaced.

Minn. No. 169 wheat was bred by selection from a Blue Stem foundation. During the first four years it was in our field tests it averaged 4.9 bushels more than the parent wheat, as displayed by the following table of average yields, showing an increase over its parent variety of twenty per cent:—

Minn. No. 169	28.5	bushels
Minn. No. 51	23.6	"
Gain	4.9	"

In 1902, this wheat was sent in four-bushel lots, at $1.50 per bushel, to three hundred and seventy-five farmers. Eighty-nine reports gave comparisons that were fair both to the new and old wheats, and there were obtained the following average yields, showing an increase over the common wheats for the entire State of eighteen per cent:—

Minn. No. 169	21.5	bushels
Common wheats	18.2	"
Increase	3.3	"

In 1903, more than 150,000 bushels of this wheat were grown, most of which will be used for seed in 1904.

Similar results have been secured with flax. Seven years ago, Professor Hays chose seven samples of the common Minnesota and Dakota flax, and made by selection many new types for the production of seed, and numerous other types, especially for production of fibre. The following table gives the general results for 1902:—

	Yield of grain.	*Yield of straw.*	*Height in inches.*
Av. of 4 best varieties selected for seed	17.8	1.40	23
Av. of 4 best varieties selected for fibre	10.5	1.76	35
Av. of 4 best common varieties (from outside sources)	11.9	1.52	24
Increase	5.9	.24	. . .

In field trials, in 1902, the increased yield of flax per acre of the new varieties bred for seed was forty-nine per cent; and the increased height of the new varieties bred for fibre was forty-six per cent more than the common flax.

"We have developed statistical methods," Professor Hays writes, "of dealing with such plants as wheat, alfalfa, corn, and, in fact, nearly all of the field crops where it is necessary or very advantageous to plant a single seed in a hill, that selections may be made and the breeding powers of parent plants measured. The general features of this statistical work may be stated as follows: Every acquisition or newly bred variety receives a number written thus, 'Minn. No. 13 corn,' for example. It is also botanically described and the facts concerning its history, name, description, etc., entered in our 'Minnesota Number Book.' If the newly secured variety is an exceptionally promising one, it is put into field tests, but ordinarily in the preliminary garden test the first year. Promising acquisitions and promising newly bred hybrid stocks are entered in the nursery, where their breeding by rigid selection is begun, and large numbers of plants are grown, one in each hill, giving each plant the same space and opportunities as each other plant. By processes of elimination, the few best performers are secured. The next year we plant a large number of the progeny of each of these superior mother-plants. The average yield, height, and other measures are taken of the progeny of each mother-plant. The breeding value of each mother-plant is thus secured in terms of the average performance of the progeny;

these are better measures of breeding power than are the measures of mere performance of the individual. These tests of the breeding values of the mother-plants are continued two and sometimes three years. Seeds from parent plants producing the best average progeny are used alone or in mixtures of close-pollinated species, and in mixtures in open pollinated species as the foundation of new varieties. These are tested in the field with the parent and other best standard varieties for three years. Any introduced or newly bred variety which is an especially good yielder of value per acre is sent to the coöperating State Experiment Stations in surrounding States and to our substations, and its quantity is rapidly increased. Any variety that is specially promising after being tried for, say, two years at several stations, is increased to sufficient quantity to sell to a number of farmers in each county in the State. This seed, backed by all the force of pedigree that we can command, is sold at a high price, so as to make the seed business profitable, and men are induced to raise it and sell large quantities at a price which will yield them a profit."

A most gratifying augury of the coming type of effort is to be found in the work of the Plant-Breeding Laboratory of the national Department of Agriculture. This is an organization effected for the purpose of producing types or kinds of plants that shall meet particular requirements. Its work is now proceeding with many groups of plants, but the burden of all its effort is efficiency in the final product. Its work with cotton promises to do nothing less than to revolutionize the cotton industry. The special difficulty with the present Upland cotton is the shortness of the "staple" or fibre. This inch-long staple sells at present (1903) for eight to eight and one-quarter cents a pound, whereas the long staple of the Sea Island cotton sells for twenty-five to thirty cents per pound. The effort is to secure a longer staple for the Upland, either by crossing it with the Sea Island or by working with some foreign long-staple type. The Egyptian cotton has a long staple, and this is now being used as one of the foundation stocks. But the Egyptian cotton possesses faults along with its long staple. It will be the work of years, by means of careful selection, to augment or maintain the desirable qualities and to eliminate the undesirable qualities; when this is done, the cotton will no longer be the Egyptian, but practically a new creation, and this new creation should receive a new name in order to distinguish it from the inferior Egyptian from which it will have had its birth. Under the leadership of Mr. Webber, this new plant-breeding enterprise (probably the largest in the world) is now extended to citrous fruits, apples, pineapples, oats, tobaccos, and other crops; and there is every indication that its usefulness will expand greatly within the immediate future. Other institutions, and other divisions of the Department of Agriculture, are conducting similar work. In fact, one or more officers at nearly every experiment station are now giving attention to some phase of plant-breeding work. It is significant that effort is now being given to the improvement of the staple farm crops, whereas a few years ago plant-breeding work was supposed to belong mostly to the horticulturist. Time is now on when every resourceful farmer must look to the improving of the intrinsic merits of his crops.

The modern methods of plant-breeding demand, first, that the breeder shall familiarize himself thoroughly with the characteristics of the group of plants with which he is to work. He must have very specific and definite knowledge of what makes the plant valuable and what its shortcomings are. Then he must secure as starting-points plants that give promise in the desired direction. Thereafter his skill will be taxed in selecting along responsive lines, in making accurate and significant statistical measures, in devising workable systems of testing. He must grow large numbers of plants, if he is working with farm crops, in order to multiply his chances of securing desirable variations and to minimize the errors.

A promising course of breeding is one that shall develop disease-resisting races within the variety. Considerable progress has already been made in this direction with cotton, oats, and some other crops. Now and then a hill or a row or a variety of potato resists the blight. Why? May it not be used as a starting-point for the development of a blight-resistant strain? The producing of disease-resisting and pest-resisting races is one of the most promising lines of work in the new plant pathology.

Nor are all these advances to be secured from seed selection alone. The cuttings and grafts of fruit plants perpetuate the parental characteristics with a good degree of surety. The time must soon come when it will not be sufficient to multiply the Bartlett pear from the Bartlett pear. We shall still further specialize our ideals and propagate from particular Bartlett pear trees that have made record performances. This subject is being tested in New York and elsewhere. It is one of the most important problems now before the nurseryman and orchardist.[1]

All this plant-breeding work is especially of a kind to demand governmental support. The prog-

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[1] See, for example, a discussion of this subject in a paper on "The Whole Question of Varieties," in the Report of the American Association of Nurserymen, 1903 (Detroit convention). The subject is also discussed in "Survival of the Unlike."

ress of invention can be left to private initiative, because the person can patent his device and secure all the financial returns that it is worth. A variety cannot well be patented or controlled. This is particularly true of these great race improvements, in which no distinct and namable variety results; and these race improvements are the very ones that are most likely to be of greatest benefit to agriculture and therefore to the nation.

These methods and ideals may all be summed up as follows: —

I. Determining on what the merit in any group of plants depends, and finding out what is needed to make the plants more efficient. What makes a potato "mealy"?

II. Securing a start in the desired direction by

  (*a*) Choosing for seed-bearing any plants that are promising;

  (*b*) Introducing prominent foundation stock from other regions or foreign countries;

  (*c*) Crossing for the purpose of injecting a new or better character into the strain.

III. Continued selecting, careful testing, and keeping accurate statistical measurements and records to maintain the progress true to line.

The first thing that strikes one in all this new work is its strong contrast with the old ideals. The "points" of the plants are those of "performance" and "efficiency." It brings into sharp relief the accustomed ideas as to what are the "good points" in any plant, illustrating the fact that these points are for the most part largely fanciful, are founded on *a priori* judgments, and are more often correlated with mere "looks" than with efficiency. An excellent example may be taken from corn. In "scaling" any variety of corn, it is customary to assume that the perfect ear is one nearly or quite uniformly cylindrical throughout its length and having the tip and butt well covered with kernels. In fact, the old idea of a good variety of corn is one that bears such ears. Now this ideal is clearly one of perfection and completeness of mere form. We have no knowledge that such form has definite correlation with productiveness, hardiness, drought-resisting qualities, protein, or starch content — and yet these attributes are the ones that make corn worth growing at all. Such ears may be more productive of kernels, but they may not be characteristic of plants that produce the greatest number of large ears. It may be distinctly worth while to breed for this perfection in form, providing it is associated with breeding for efficiency. An illustration also may be taken from string beans. The ideal pod is considered to be one of which the tip projection is very short and only slightly curved. This apparently is a question of comeliness, although a short tip may be associated in the popular mind with the absence of "string" in the pod; but we do not know how much this character is related to the efficiency of the bean pod. We are now undergoing much the same challenging of ideas respecting the "points" of animals. These "points," by means of which the animals are "scored," are often merely arbitrary. Now, animals and plants are bred to the ideals expressed in these arbitrary points, by choosing for parents the individuals that score the highest. When it becomes necessary to recast our "scales of points," the whole course of evolution of domestic plants and animals is likely to be changed.

We are to breed not so much for merely new and striking characters that will enable us to name, describe, and sell a "novelty," as to improve the performance along accustomed lines. We do not need new varieties of seedling potatoes so much as we need to improve, by means of selection, some of the varieties that we already possess. We are not to start with a variety, but with a plant. It is possible to secure a five per cent increase in the efficiency of our field crops; this would mean the annual addition of hundreds of millions of dollars to the national gain.

The purpose, then, of our new plant-breeding is to produce plants that are more efficient for specific uses and specific regions. They are to be specially adapted. These efficiency ideals are of six general categories: —

1. Yield ideals.
2. Quality ideals.
3. Seasonal ideals.
4. Physical conformation ideals.
5. Regional adaptation ideals — as to climate, altitude, soil.
6. Resistant ideals — as to diseases and insects.

The main improvement and evolution of agriculture are going to come as the result of greater and better crop yield and greater and better animal production. It is not to come primarily from invention, good roads, rural telephone, legislation, discussion of economics. All these are merely aids. Increased crop and animal production are to come from two agencies: improvement in the care that they receive; improvement in the plants and animals themselves. In other words, the new agriculture is to be built upon the combined results of better cultivation and better breeding. So far as the new breeding is concerned, it is characterized by perfect definiteness of purpose and effort, the stripping away of all arbitrary and factitious standards, the absence of speculative theory, and the insistence upon the great fact that every plant and animal has individuality.

Mendelism is maize. The first crossing was made in 1900, Stowell Evergreen being pollinated by Indian Flour corn. The ear resulting from this cross (1900) presented in color and composition the characteristics of Indian Flour corn. This ear was planted in 1901. Some plants were pollinated in 1901 with Stowell Evergreen (one of the resulting ears shown at left) and some with the hybrid itself (a resulting ear on the right). — PLANT-BREEDING, LABORATORY, UNITED STATES DEPARTMENT OF AGRICULTURE.

LECTURE V.

CURRENT PLANT-BREEDING PRACTICE.

[Contributed to the Fourth Edition, 1906.]

ONE of the "signs of the times" in North America is the attention that is being given to the practical breeding of plants. The academic discussion of the subject is now well past, and a host of persons is actually at work. Results are accumulating rapidly with very many kinds of plants; but most breeders are too busy with their entertaining work to stop long with philosophy or speculation. Eventually, of course, we shall be able to formulate somewhat definite statements as to how to proceed to secure desired results, and then the literature of plant-breeding can be intelligently rewritten. However, there is no hope that plant-breeding can ever proceed with such exactness as to enable us to produce forthwith the things that we desire, in the way in which the mechanician devises new machines, notwithstanding all the suggestions of persons who write with much self-assurance. For all that we can now see, plant-breeding will always be an experimental process.

It is this very experimental uncertainty of the work that gives it much of its charm to inquisitive and sensitive minds.

In considering the American achievement in plant-breeding, we must divest ourselves at the outset of all idea of "wonder," and "miracle," and other nonsense, which has been so much written into the subject in very recent time. Plant-breeding is a plain and serious business, to be conducted by carefully trained persons in a painstaking and methodical way. It is not magic. There are persons who have unusual native judgment as to the merits and capabilities of plants and who develop great manual skill; but they are plain and modest citizens, nevertheless, and their methods are perfectly normal and scrutable. The wonder-mongers are the reporters, not the plant-breeders.

It is a curious psychological phenomenon that the populace, or a certain part of it, seems to lose its head now and then. This phenomenon is not peculiar to politics. It enters those domains that are compassed by fact and that in ordinary times are dominated by common sense. Plant-breeding has been seized of this sensationalism. Newspapers, magazines, and books have spread the most wonderful tales. The lay writers have at last awakened to the fact that great progress is making in agricultural subjects, and, with a fragmentary and superficial view here and there, have written of the subjects with all the enthusiasm and partiality of new discovery. I have now in mind not only the inflated writing about plant-breeding, which constitutes a regrettable contribution to current horticultural literature, but also that general tendency to exploit everything that is capable of high coloring. I fear that the agricultural historian, when he takes account of the exploitations of the present day, will recall other stages in which we seem temporarily to have lost our better judgment, of which the *Morus multicaulis* craze and the lightning-rod boom are examples in two previous generations.

Having now warned my reader that I have nothing marvellous in store, I shall proceed to indicate some of the ways in which American plant-breeders are working, fully conscious that the space at my disposal is much too little to allow of any adequate presentation of the subject. It may not be out of place to call the reader's attention to the three foundations on which rests the increased productiveness of crops and animals: —

The enrichment of the land;

The tillage and care;

The producing of better varieties and strains.

We have long given careful attention to the first two; now we are studying the third with new enthusiasm and purpose. There recently has been organized an "American Breeders' Association," of which three conventions have now been held. The proceedings of the first two meetings are published in one volume, and the list of members constitutes a breeders' directory; this list contains seven hundred and fifteen names of plant-breeders and animal-breeders. In the classified "business directory" are the following numbers interested in different phases of plant-breeding: fruit and nursery stock, forty persons; seed corn, twenty-nine persons; farm seeds, twenty-four persons. This classified list is not at all complete. The persons that are interested in the breeding of flowers alone are probably more numerous than all of these.

Local crop-breeders' societies are also being organized. The "Nebraska Corn Improvers' Association" met recently at Lincoln, with the following papers on the programme: —

Breeding Cereals, Prof. C. A. Zavitz, Guelph, Ontario.
Breeding Timothy, Dr. A. D. Hopkins, Washington, D.C.
The Corn Plant as affected by Rate of Planting, E. G. Montgomery, Nebraska Experiment Station.
Practical Corn Breeding on a Large Scale, J. Dwight Funk, Bloomington, Ill.
Fundamental Requirements for Grain Breeding, Prof. M. A. Carleton, Washington, D.C.
Breeding Drouth Resistant Crops, R. Gauss, Denver, Col.
Value of Corn Pollen from Suckers *vs.* from Main Stalks, C. P. Hartley, Washington, D.C.
Experiments in Wheat Breeding, Alvin Keyser, Nebraska Experiment Station.

The most methodical plant-breeding is now being done by officers of the experiment stations in the United States and Canada, and by the United States Department of Agriculture. In most of the experiment stations there is one person interested in improving horticultural plants and another interested in field crops; as there is an experiment station in every state and territory and in the provinces of Canada, it will be seen that there are more than one hundred persons who, by their profession, are directly concerned in plant-breeding, aside from a number of persons in the Plant-breeding Laboratory of the United States Department of Agriculture who devote themselves exclusively to this work, and not counting many persons in other branches of the Department who devote more or less of their energies to such subjects. The work is extended, also, into the hands of various assistants in the different institutions; so that it is probably no exaggeration to say that three hundred professional investigators are now giving attention, for a greater or less part of their time, to measures for improving American crop production by means of breeding. Aside from this, plant-breeding is now a subject for instruction in many of the agricultural colleges, and in this way the impulse is carried far and wide over the country.

Long before these professional experimenters began their work, however, patient and painstaking men had been breeding plants. They were "practical" men; that is to say, they bred varieties in order that they might sell the stock. Consider the number of named varieties, in the catalogues, of cabbages and tomatoes and dahlias and roses and strawberries: all these originated somewhere, and somebody named them and introduced them. To be sure, many of these varieties were discovered amongst other plants, no one knowing how or why they came; but many of them, particularly in the roses and other florists' plants, were carefully bred; and even the fortuitous varieties were often improved and "fixed" by subsequent selection. If one is to sell a novelty, he must name it. The tendency, therefore, was to produce a form distinct enough in general external characters to be easily distinguishable; that is, to produce "varieties." The experiment station man, however, is not pressed by the necessity of selling his product. Therefore he cares little for merely producing a new variety; he may think it more important to improve some existing variety or to intensify some character that is not usable in general catalogue descriptions: in short, he seeks for efficiency and not for mere characters. This type of effort was explained in the third edition of this book, and the description will still be found in the pages between 203 and 226. One might write a book on the plant-breeders who gave us the good old varieties that we still prize, working quietly and obscurely long before the days when periodicals cared to discuss the subject or before men of science condescended to investigate it. The production of varieties in those days was regarded as a trade secret, and this in part accounts for the small knowledge that we have had of the subject. I well remember the air of mystery that attached to the subject when I first began to inquire into it, and the great difficulty of securing any publishable data even when I wrote this book ten years ago; but now the field is open and free, many ardent young fellows are exploring it, and if I were to write again, I should be bewildered by the facts and instances that I should find.

Before proceeding to the discussion of details, I may be allowed to remind the reader of the processes or stages in plant-breeding: —

1. To determine what attributes it is desirable to work for;
2. To secure a variation;
3. To improve and concrete the variation, if need be, by selection.

It matters not whether the breeder is Darwinian or De Vriesian, the methods are practically the same. Even if varieties are mutants, as De Vries supposes, —forms small or great that originate full-fledged, — we may still need to practise selections as between mutants; and if any varieties turn out to be amenable to further separation by means of selection, it only proves that these particular forms are not mutants. If a form is so well marked and so valuable and so constant that it needs no selection, then the breeder may rejoice that his task is so easy, and he should have sufficient time and enthusiasm left to cause him to desire to repeat the experience. Howbeit, if the plant-breeder's realm lies with plants that he must propagate by means of seed, selection is usually the one essential to success. How the variations or differences are to be secured in the first place, — whether by change of soil or climate, hybridization, or the less arduous method of merely watching for them if perchance they are in the mood to appear, — is a question to be settled each man for himself; and he will likely find that there is no royal road, and in consequence he will try all methods and keeps his eyes open in the bargain. The greater the number of plants on which he experiments, the greater will be the likelihood of securing useful variation, and the more freely can he select; all recent experience enforces this fact.

By selection he hopes to cut off the undesirable forms and to cause the stock to "come true" to seed; and he may also be able to intensify his characters at the same time. To "come true," means that the particular attribute or form becomes hereditable. Sometimes the form is hereditable in the beginning. I happen to have photographs showing such an example. It is the case of two red-root pigweeds, *Amarantus retroflexus*, that grew in such a jostle of weeds that they had to take on different size and shape in order to live. A fuller account of these two pigweeds can be found on pages 258 to 263 of "Survival of the Unlike"; it is now sufficient to say that one of them got headway above its neighbors and measured thirty inches in spread and twenty-four inches

FIG. A.—The big pigweed, after frost.

in height, and that the other had a spread of nine inches and a height of twelve inches. The framework of the larger plant is shown in Fig. A. Seeds from both plants, equally mature to all appearances, were carefully sown in pans in the greenhouse ; those from the smaller plant germinated poorly, as seen in Fig. B ; and when the plants came into bloom, there was still a marked difference, as shown in Fig. C. I have no reason to doubt that these differences would have been again hereditable to some degree had I sown the seed ; but as I had not set out to produce an improved strain of pigweed, I did not carry the test farther. All this suggests a method of securing such a plant as you may want.

The material for new types of plants may be (*a*) the varieties already in use, (*b*) species or varieties introduced from foreign parts, (*c*) native plants not yet domesticated, (*d*) hybrids. In the introduction of foreign plants, the past few years have been fertile. These plants are introduced primarily for their intrinsic merits ; but almost immediately they are established in the new country, they begin to change or vary, and soon form the basis of new direct forms or of hybrids. These foreign plants are being brought in by commercial firms, well-to-do plant fanciers, botanic gardens, experiment stations, but particularly by the United States Department of Agriculture, which has or-

FIG. B.—Seedlings from the small pigweed at the left, and from the big one at the right.

FIG. C.—The pigweeds at blooming time. The parental characteristics—apparently the work of a single generation—are shown to be hereditable.

ganized for this purpose the "Office of Seed and Plant Introduction and Distribution," in charge of David Fairchild. This office introduces promising plants from all parts of the world, and subjects them to test on the grounds of the Department of the various experiment stations, and on the premises of private persons. Over fourteen thousand selected entries appear on the inventory of the office. Some of these entries are species new to the country; but most of them are new or untried forms of species already growing in North America. In many ways our domestic flora is being enriched from outside sources, and these additions in time will give rise to a variable progeny, or will furnish strong stock for hybridization, and will affect the course of plant-breeding.

I. Luther Burbank.

An editor of one of the great magazines asked me recently whether Luther Burbank were the only plant-breeder in the country. One who has read the current Burbankiana can well understand why the question was asked. If any reader has followed me this far, he will not need to ask a similar question.

Yet if there are other plant-breeders, Luther Burbank stands alone. He is a private person, pursuing his work in his own way, and because he loves it so well that he cannot forego it. He is a gardener of a new kind. Every plant appeals to him. This appeal is quite unlike the appeal that is made to the botanist or even to the horticulturist; Burbank likes it because it is a plant and because he would like to try to modify it. Therefore he grows everything he can, no matter where it comes from or of what kind. He cultivates with personal care, multiplies the stock to the limit of his capacities, scrutinizes every variation, hybridizes indiscriminatingly, saves the seeds of the forms that most appeal to him, sows again, hybridizes and selects again, uproots by the hundreds and thousands, extracts the delights from every new experience, and now and then saves out a form that he thinks to be worth introducing to the public. Every part of the work is worth the while of itself; at every stage the satisfaction of it is reason enough for making and continuing the effort. Every form is interesting, whether it is new or the reproduction of an old form. He shows you the odd and intermediate and reversionary forms as well as those that promise to be of use to other persons.

In all this there is neither magic nor conjuration. The methods are the common practices of all good plant-breeders, made unusually efficient, perhaps, by the geniality of the climate, the great scale on which some of the work is conducted, the wide variety of plants under experiment, and the

FIG. D. — Some of Burbank's frames and garden beds.

FIG. E. — Gardens at Luther Burbank's.

patient skill and good judgment of the man. He cares little for the scientific method, so long as the plants produce new forms. He will try to cross anything, no matter whether it has ever been crossed before or whether the crossing is in utter disregard of all acknowledged botanical relationships. Once when I asked him the botanical name of a plant, he replied that he did not know and did not care to know; for if he knew he would likely be bound by the book statements and he might be handicapped in his work. He is a bold worker, and this accounts for some of the odd results.

Mr. Burbank is a plain, modest, sympathetic, single-minded man. He is not a wizard. The reporters have got hold of him and have abused their privileges because they have not known how to measure him and have not understood him. Perhaps he has not understood himself. He is kind-hearted and obliging; he has been drawn into discussions of all kinds of subjects, some of which nobody knows anything about; and persons have been led to think that he has occult knowledge. So far as these write-ups have tended to draw attention to the kind of work that he is doing, they undoubtedly have served a useful purpose; but many of them have really misrepresented the genius of the man. Luther Burbank stands for a great new idea in American horticulture, and it is time that we begin to recognize what this is.

The practical results that Mr. Burbank has secured have been praised beyond all reason. His place abounds in interesting and surprising things, just as would be expected of any other man's place if conducted under similar conditions. His work has been so much written about that it is not necessary to try to make any catalogue of the things that are under his hand. The number of really useful things that have been introduced by Burbank is proportionally small; although it is not too much to hope that some of his productions, as the plumcots, may be the starting points of strong and novel lines of evolution. Some of those that have been most heralded are of doubtful economic value. This is true, I think, of the much-vaunted spineless cactus. Several species of opuntia (to which genus Mr. Burbank's spineless cactus belongs) are spineless. Spineless cacti have long been known in Mexican and other gardens. By continued selection the more or less spineless forms can be singled out and the smooth character perhaps intensified. Mr. Burbank may be able to eliminate the small spicules and to improve the plant in the edible qualities of its fruit and stems. There is no doubt that he has the spineless cactus in quantity (Fig. F). It is a pleasure to see him rub his face against the pads to deter-

FIG. F.—Spineless and spine-bearing cacti at Burbank's.

mine whether the spines are really there. But what use shall we make of it? It is said that we shall plant the deserts, for the cattle can eat this spineless cactus, and thus will the food supply of mankind be immensely multiplied and the welfare of the race enhanced. The cattlemen now singe the spines from the wild cacti by means of gasoline torches, and this is much cheaper than to plant the desert; and experiments show that if the desert were planted with spineless cacti, the young plants would be destroyed if the cattle and jack-rabbits were allowed on the ranges: this would mean fencing the deserts. If the spineless cacti are grown from seeds, some of the progeny will probably be spiny; these and the native seedlings will have to be uprooted and this will probably entail more expense than the enterprise will be worth. If, in addition to this weeding, the plants are set out from cuttings, the desert becomes practically a cultivated ground. Moreover, it is undetermined whether Mr. Burbank's cactus is really a desert form. Some of the deserts will be irrigated and then cacti will not be wanted; and if the deserts are to be planted at all, it is a question whether cacti are the best plants with which to stock them.

All this leads me to say that the value of Mr. Burbank's work lies above all merely economic considerations. He is a master worker in making plants to vary. Plants are plastic material in his hands. He is demonstrating what can be done. He is setting new ideals and novel problems. Heretofore, gardeners and other horticulturists have grown plants because they are useful or beautiful: Mr. Burbank grows them because he can make them take on new forms. This is a new kind of pleasure to be got from gardening, a new and captivating purpose in plant growing. It is a new reason for associating with plants. Usually I think of him as a plant-lover rather than plant-breeder. It is little consequence to me whether he produces good commercial varieties or not. He has a sphere of his own, and one that should appeal to a universal constituency. In this way, Luther Burbank's work is a contribution to the satisfaction of living, and is beyond all price.

II. A Practical Plant-breeder.

There are many wise and humble folk in many parts of the country who are making efficient history in plant-breeding. I often feel that I should like to hunt them out and make them known to the world. They are mostly plant-lovers, whose chief reward is the joy that they derive from the work. I was struck with this many years ago when making a study of the evolution of the native plums, for patient souls had been at work on these fruits for years almost unknown of the world at large, and had produced numbers of useful varieties; and I have been similarly impressed in other excursions into plant evolution fields.

There is another class of practical men who do their work on a larger scale as a part of a thoroughgoing and well-known business enterprise. Such a business I am now to portray. I choose this particular instance only because I am somewhat familiar with it and because it is near home. I had this man in mind when I wrote the lines on beans on pages 135 and 136 of this book.

N. B. Keeney, Leroy, New York, was first a farmer. In war time he engaged in the produce business in Leroy, in a farming community. There was good trade in beans. The son Calvin N. Keeney became interested in the varieties of beans. He was attracted by their behavior in the field, and he began experiments to improve them by means of selection. From this it was but a step to the originating of new varieties. The son was taken into the business, the firm becoming N. B. Keeney and Son. The father is now dead, but the son continues the business. The business is primarily the growing of seed for seedsmen. It is devoted entirely to beans and peas. About two thousand acres in New York are devoted to beans, and four thousand acres in Michigan to peas.

In connection with the seed business is a canning factory, putting up beans, peas, and sweet corn.

The straw, husks, and other refuse could not be sold to advantage. It required an expenditure of five hundred dollars a year to dispose of the waste. In order to utilize this waste of the seed and canning businesses, a stock-feeding enterprise was established. The green pea vines, and corn refuse are ensilaged. The bean straw is fed to sheep. At present, the stock feeding comprises about one hundred and fifty hogs, three hundred steers, fifteen hundred sheep. These statements are made in order that the reader may see how far a bean-breeding and pea-breeding enterprise may lead.

The main effort of the Keeney seed business is given to growing the leading varieties in quantity; for in order to hold the best trade, it is necessary to keep every variety up to standard or even to improve it: therefore the entire enterprise becomes a practical plant-breeding business. Now and then new varieties are bred up and introduced; and improved strains of old varieties are offered, often replacing entirely the old strains. In 1905 the following varieties of beans were grown in quantity; those marked with one star (*) are improved or selected strains, and those with a double star (**) are varieties of the Keeneys' originating: —

Best of All.
Bismarck, Buist's.
Black Wax, Challenge.
*Black Wax, Cylinder Pod.
**Black Wax, Fuller's.
*Black Wax, Imp'd Prolific.

**Black Wax, Pencil-pod.
Bountiful.
**Brittle Wax.
Brown Bunch.
**Butter Wax, Maule's.
Champion Bush, Low's.
China Red Eye.
Crystal Wax.
Davis Wax.
Emperor of Russia.
Flageolet Wax, Crimson.
Flageolet Wax, Purple.
Golden Crown Wax.
Golden Eyed Wax.
Golden Wax, Grenell's Imp.
Golden Wax, Orig. Strain.
**Golden Wax, Keeney's Rustless.
Goddard or Imp. Hort. Dwf.
Hodson Wax.
Horticultural Dwarf.
Hort. Dwarf, Carmine Pod.
Hort. Pole, Worcester Imp.
Hort. Pole, Gold. Carmine.
Hort. Wax, Rawson's.
Imperial Wax, Allen's.
Imperial Wax, Jones's.
Kidney, White.
Kidney Wax, Wardwell's.
**Kidney Wax, Round Pod.
Longfellow.
Marrowfat, White.
*Medium, Burlingame's.
Mohawk, Early.
**Mohawk Wax.
**Pea Beans, Boston Small.
Pea Beans, Snowflake.
Perfection Wax.
Prolific, Powell's.
Prolific, Southern.
Refugee, Extra Early.
Refugee, Golden.
Refugee, McKinley.
Refugee, Round Pod or 1000 to 1.
Refugee, Silver.
*Refugee Wax, Keeney Stringless.
Rust Proof Wax, Currie's.
**Saddle Back Wax, Burpee's.
Scotia.
Six Weeks, Long Yellow.
Six Weeks, Round Yellow.
**Stringless Green Pod, Burpee's.
**Stringless Green Pod, Giant.
Valentine Black.
Valentine Ex. Ey. Red.
*Valentine, Ex. Ey. Ex., Round Podded Red.
Valentine, Hopkins's Red.
Valentine, White.
Warren Bush.
White Wax.
**White Wax, Burpee's New Stringless.
White Seed Wax, Jones's.
**Yosemite Mammoth Wax.

This list is interesting as showing the proportion of new or original to old or other varieties in a practical seed-breeding establishment. This list does not represent the whole number of varieties that Mr. Keeney grows, for the seed-breeder must test every new thing in his line and always be on the lookout for the chance to better the kinds that are in existence. Every year Mr. Keeney grows about two hundred kinds of beans in the test garden; and sometimes as many as six hundred different lots — some of them representing different stocks or strains of the same variety — are grown and studied.

To make any intelligent headway in breeding beans, the breeder must first know beans. He must know what the people want, what it is possible to get, and all the good points and bad points of beans as to root and top, and bloom and pod and seed. This will prevent laborious mistakes and economize much enthusiasm to be put into progressive work. Then he will look for natural sports that have some or all of the desired qualities; thereafter the process is one of most rigorous selection until the stock breeds true. If the desired form or start does not appear, it may be necessary to set it off by crossing plants that have some of the desired characteristics; thereafter the process is one of selection, as before. Mr. Keeney says that he can increase or intensify a characteristic by means of selection, as well as eliminate the undesirable features. This is the whole plan of Mr. Keeney's work. There is no mystery about it; but there is judgment of a kind that few men possess and a persistent process of selection such as few men have the heroism to maintain.

If the breeder burns with a desire to have forms so distinct that he can attach a new name to them, he must caution himself at every point, else he will be introducing things before they are ready or which are of no gain to the world. New varieties of seed vegetables come slowly; and if they are not well bred (that is, not well selected), they will very soon break up into other forms or "run out." Mr. Keeney puts his main effort in keeping the old varieties up to grade, and it is on these varieties that he makes the business pay. The making of new kinds of beans pays only in the intellectual satisfaction of it, and in the general standing that it gives the business. Mr. Keeney tells me that if he had never accomplished anything else in the breeding of plants, he would be content with having produced the Burpee Stringless Green Pod.

To keep the stock up to grade, it is necessary to begin with seed that is not only "true to name," so far as general varietal characteristics are concerned, but that is vigorous and with strong hereditary or carrying-over power. This seed is planted on well-prepared land that is adapted to beans. The tillage and general care must be of the best. The plantation is gone over with great care for "rogues" or untrue plants; these are pulled out. The thoroughness and consistency with which the "roguing" is done, will determine the result. This process is continued every year; and if one field or one man's growing gives a better stock than any other, this product is used as stock-seed for all fields next year: thus the stock is always being renewed and rebred. Sometimes a single plant will be unusually good, and from this the whole stock may be renewed. For example, all the Mammoth-podded Sugar peas grown in America to-day came from a teaspoonful of seed that Mr. Keeney planted some ten or twelve years ago.

Some fifteen or twenty years ago, Mr. Keeney found in a field of White Wax beans one plant that bore black seeds in stringless white pods. In three or four years he had saved a quart of promising seed. He planted this seed in an isolated rich farm garden. All came true but one plant: this plant was very tall and rank, and was green-podded. From this plant twenty-two varieties were produced, some of which were good enough to save and introduce. From the bulk of the original quart that came true, Mr. Keeney produced the Yosemite Mammoth Wax, which is now a standard variety. The introducing of the "stringless" character into his beans has come about very largely by crossing with the Yosemite.

In peas, Mr. Keeney grows the following list in quantity (he has specially selected strains of those marked with a star *) : —

Abundance.
Admiral.
Admiral Dewey.
Advancer.
Alaska.
Ameer.
American Champion.
*American Wonder.
British Wonder.
Champion of England.
Claudit.
Daisy, Carter's.
Duke of Albany.
Duke of York.
Dwarf Champion.
Dwarf Telephone.
Empire State.
English Wonder.
Everbearing.
Excelsior, Gregory's.
Excelsior, Nott's.
*Extra Early, Pedigree.
Extra Early, Trial Ground.
First and Best.
Forcing, Sutton's.
Forty Fold.
Glory.
*Gradus or Prosperity.
Green Gem, Sutton's.
Heroine.
Hurst, William.
Ideal, Sutton's.
Juno.
King of the Dwarfs.
*Laxton, Thomas.
Long Island Mammoth.
Market Garden, Horsford's.
Marrowfat, Black-eyed.
Marrowfat, Early Marblehead.
Marrowfat, Improved Sugar.
Marrowfat, White.
May Queen.
Perpetual.
Premium Gem.
*Pride of the Market.
Prince of Wales.
Profusion.
*Prolific Early.
*Prolific Early Market.

Prolific, Laxton's.
Prosperity or Gradus.
Reliance, Hurst's.
Seedling, Sutton's.
Senator, Improved.
Shropshire Hero.
*Stratagem.
Sugar, Dwarf Gray.
Sugar, Very Dwarf.
*Sugar, Mammoth Podded.
Sugar, Tall Gray.
Surprise, Gregory's.
Telegraph (L. I. Mam).
*Telephone.
*Tom Thumb.
Yorkshire Hero.

The familiar Extra Early garden pea has been a subject of very careful breeding. The "Pedigree" strain has a continuous genealogy running back to 1890. In that year, it became apparent to Mr. Keeney that the general stock of this well-known variety was much mixed and run down. He therefore selected out a good stock, and soon developed some twenty-four "families" or lines of this variety; from these he later selected three lines, which were equally desirable, and represented very closely his ideal of what the Extra Early should be. He still keeps up the selection; and two or three times has discarded all his general seed-stock which he had himself produced, and has renewed the stock with a strain that he had been breeding up in the meantime. The work of choosing the initial departures and of making the primary seed-stock selections cannot be left to hired men; in fact, there are very few foremen or assistants who have the judgment and patience for the work: it must be a labor of love. Most persons do not have the courage to discard so many plants. Mr. Keeney says that the success in seed-breeding lies in what you throw away.

The satisfactory prosecution of all this work requires careful note-taking. Mr. Keeney furnishes, for example, such information as that given on page 256 for his customers, all taken directly from field notes.

There must also be personal records of the strains and stocks that are under manipulation. Mr. Keeney has kept the notes of his bean breeding in a specially prepared record book, with the entries running across two facing pages. The headings of the various columns on these two pages suggest the kind of information that the breeder desires to have. (See page 257.)

III. The Experiment Station Work.

Most of the agricultural experiment stations — and there is one to every state, territory, and nearly every Canadian province — are interested in concrete pieces of plant-breeding work. Through the extension work of these stations and of the agricultural colleges, the plant-breeding conception is being carried to the people. These institutions are distributing selected and highly bred seeds, and are instructing their correspondents in the importance of quality in seed stock and the conditions that modify that quality. Perhaps the most fruitful extension work of this

VARIETIES.	REMARKS.	Days from planting to first picking.	NOTES CONCERNING PODS.		NOTES CONCERNING VINES.	
			Usual length of pods in inches.	Usual width of pods in fractions of an inch.	Usual height with ordinary field culture.	Usual height with garden culture.
					Inches.	Inches.
Excelsior, Nott's	Fine. Even growth	63	$2\frac{7}{16}$–$2\frac{1}{2}$	$\frac{1}{2}$–$\frac{11}{16}$	10–12	12–14
Extra Early	Good	49	$2\frac{3}{8}$–$2\frac{1}{2}$	$\frac{1}{2}$–$\frac{9}{16}$	20–26	24–30
Extra Early	Fine. Even growth	49	$2\frac{3}{8}$–$2\frac{1}{2}$	$\frac{1}{2}$–$\frac{9}{16}$	20–26	24–30
Trial Ground Strain						
First and Best	Fair grade. Extra Early	50	$2\frac{5}{16}$–$2\frac{7}{16}$	$\frac{1}{2}$–$\frac{9}{16}$	20–28	22–32
Forty Fold	Improved Champion	79	$3\frac{1}{4}$–$3\frac{1}{2}$	$\frac{5}{8}$	40–46	44–52
French Canner	Productive. Fair quality	80	3 –$3\frac{1}{2}$	$\frac{1}{2}$	40–44	46–48
Gradus or Prosperity	Early. Fine		$3\frac{1}{4}$–$3\frac{3}{4}$	$\frac{5}{8}$–$\frac{11}{16}$	22–26	25–30
Heroine	Productive. Handsome pod	84	$3\frac{3}{4}$–4	$\frac{3}{4}$–$\frac{13}{16}$	20–24	24–30
Juno	Even Growth. Good	75	$3\frac{3}{4}$–4	$\frac{13}{16}$–$\frac{7}{8}$	18–22	20–24
Long Island Mammoth	Telegraph	67	$3\frac{1}{2}$–$3\frac{3}{4}$	$\frac{3}{4}$	38–44	42–48
Long Pod, Second Early	Very productive	53	$2\frac{3}{4}$–3	$\frac{1}{2}$–$\frac{9}{16}$	20–24	22–28
Mammoth Sugar	Fine. Productive. Edible pod				54–66	60–72
Market Garden, Horsford's	Good. Productive	71	$2\frac{1}{4}$–$2\frac{1}{2}$	$\frac{1}{2}$–$\frac{9}{16}$	24–30	30–36
Marrowfat	Choice Early Marrow				45–50	50–60
Early Marblehead						
Melting Sugar	Large edible pod	80	4–$4\frac{1}{2}$	1–$1\frac{1}{8}$	42–48	48–54
Ne Plus Ultra	Strong grower. Good quality	81	$3\frac{1}{4}$–$3\frac{3}{8}$	$\frac{11}{16}$–$\frac{3}{4}$		
Perpetual	Accurately named				40–48	44–51
Premium Gem	Good. Productive	59	$2\frac{3}{4}$–3	$\frac{9}{16}$–$\frac{5}{8}$	12–15	12–16

BREEDING NOTES. (LEFT-HAND PAGE.)

SOURCE OF SEED.				DESCRIPTION OF SEED.				DESCRIPTION OF PLANTS WHICH PRODUCED THIS SEED.			
NO.	PREVIOUS RECORD NUMBER.	GROWER OF SEED.	YEAR OF GRO'TH.	SIZE.	SHAPE.	COLOR OF GROUND WORK.	COLOR OF MARKING.	PLANT.	COLOR OF POD.	SHAPE OF POD.	**STRING** O. — None. L. — Little. S. — String. S.S. — **Strong S.**

BREEDING NOTES, CONTINUED. (RIGHT-HAND PAGE.)

WHERE PLANTED.				DESCRIPTION OF CROP.						
PLANTED IN YEAR.	BY WHOM PLANTED.	TRIAL GROUND NO.	YEAR IN TRIAL GR'D.	PLANT.	COLOR OF POD.	SHAPE OF POD.	**STRING** O. L. S. S.S.	TEST FUR-THER.	SUBSEQUENT RECORD NUMBER.	REMARKS.

kind is that conducted by the Ontario Agricultural College through the Ontario Agricultural and Experimental Union. This is an organization of officers, students and ex-students of the college. It has been in existence something more than twenty-five years. Through this union, since its organization, 37,416 experiments or tests on agriculture alone have been conducted on the farms. The college has given much attention to the testing of the varieties of farm crops. Importation of the various cereals was begun twenty-five or thirty years ago. The institution has tested more than two thousand varieties of farm crops for a term of five years or more, some of them having been followed more than ten years. The college thus has on hand a vast amount of carefully tested and selected material with which to prosecute the coöperative work. The plan has been to choose from two to four of the most successful varieties of the various farm crops and put them out among the coöperators throughout the province. The college has under test at the present time two hundred varieties of potatoes from which selections are made for the coöperative tests. It has fifty varieties of sweet corn under study, and in nearly all of the farm and horticultural crops it is in a similar situation as regards material for the coöperative work. So far as the mere testing of varieties of ordinary farm crops is concerned, relatively little will be done in the future; but the purpose is to continue the work with strains of those varieties that are the result of careful selection at the college. Several years ago work was begun in selecting wheat, barley, oats, and other grains by individual plants and in propagating these plants until a supply was secured for the farmer. This year there were harvested two acres of oats that came from a single seed three years ago. It is remarkable that such a supply can be secured in so short a time. In 1905 there was secured a yield of 1929 pounds of barley and of 3439 pounds of oats that were the progeny of a single seed sown in 1903. It is also stated that for the more remote future the work will be with hybrids which they are now breeding with apparent success to produce more desirable types with larger yielding qualities. All tests made by the farmers are duplicated on the college grounds. It is now proposed to establish a complete set of such experiments in each county in the province, the party conducting the work to be remunerated for the actual labor involved. These statements show how extended and effective certain kinds of practical plant-breeding work have come to be.

An examination of the recent annual reports of the experiment stations in the United States show that at least twenty-eight of them report specific plant-breeding work as in progress. The plants that are mentioned comprise the following: cotton, sorghum, corn, grasses, buckwheat, millet, wheat, rye, oats, barley, eggplant, tomato, red clover, tobacco, sweet corn, sugar beet, timothy, alfalfa, potato, pea, bean, apple, peach, cherry, plum, strawberry, blueberry, grape, date, buffaloberry, currant, gooseberry, raspberry, ornamental shrubs, flowers, forest trees.

It would manifestly be impossible to give even a running sketch of all this interesting plant-breeding work. Results may not be forthcoming as rapidly as we would like, but it is apparent that such an amount of effort concentrated on one general line of effort is bound to accumulate surprising results in the years to come. Merely as examples of the nature of the problems lying in this unexplored field, I insert a brief description of two pieces of breeding work now in progress and very different in kind.

Breeding Hardy Fruits for the Prairie Northwest.

By N. E. Hansen.

There are three headings under which this subject may be considered: (1) importation; (2) exploration; (3) amelioration. By importation we secure the best plants from other countries. In pursuance of this policy I import plants every year from various countries of the Old World.

By exploration is meant searching for desirable variations from the normal type of fruits in our native woods and prairies. I have done much of this kind of work, especially in the range country from the Missouri River west to the Black Hills. By amelioration is meant the improving of this material gathered from various parts of the world. We should take all native plants of any value and try by crossing them with desirable imported plants to secure new plants combining the desirable characteristics of both races.

Over a large area of the prairie Northwest, many of the fruits grown in the eastern and southern states are deficient in hardiness. This has been demonstrated by thousands of planters. It has been estimated that it cost over one hundred million dollars to learn that the varieties of apples from the milder climate of western and southern Europe are not adapted to this new prairie region. It begins to be evident that all this experience is another proof of De Candolle's law, that several thousand years are needed to produce a modification in a woody plant which will enable it to support a greater degree of cold. But that nature is equal to such a task is shown by the fact that woody plants, such as box elder and the red cedar, extending over a wide area, differ greatly in hardiness. The red cedar and box elder from the southern and eastern range of their limits winterkill at the northern limits, while the local form of the species is hardy. In other words, it is possible for nature through thousands of years to change the constitution of a plant as to its ability to endure greater cold, but it is not an experiment for man to undertake. Inherent hardiness must be present in at least one of the parents of the seedling; that is, hardiness cannot be secured from tender varieties by selection. It must either be present in both parents or transmitted from one parent, the same as any other characteristic. Plants can be bred more resistant to cold by crossing with some hardy species.

Methods of Work. — In general, where no crossing is done, the principle followed is that laid down by Darwin and others: "Excess of food causes variation." Choice seedlings are started in flats and transplanted to the field when large enough, in highly manured soil. In some cases it is best to sow seed thinly in nursery rows and transplant when one year old. At fruiting time the best few are selected, the remainder dug with a tree-digger and destroyed by fire.

After endeavoring in vain for several years to cross fruit blossoms in the breezy climate of South Dakota, where spring is sometimes backward and then the blossoms come on with a rush, I decided to do the work under glass. While visiting orchard houses in Europe in 1894 and again in 1897 the thought came to me that this method of raising fancy fruit could be utilized in experiments in the prairie Northwest. The applicability of this method elsewhere remains to be determined. The use of dwarf stocks is necessary as the paradise for the apple, quince for the pear, and the western sand cherry for the stone fruits. The South Dakota legislature of 1901 granted means for erecting the first fruit-breeding greenhouse ever constructed. Since then experiments have been limited only by the space available. Much more could have been done with a larger greenhouse. I trust that future legislatures will provide additional facilities. Illustrations and descriptions of these breeding houses may be found in Bulletin 88 of the South Dakota Experiment Station.

As a result of this appropriation, and the liberality of the regents of education in affording needed storage cellars and other facilities, we are able to announce the production of many interesting hybrid fruits, many of them combinations made for the first time. Some of them are hybrids of the South Dakota sand cherry with the peach, nectarine, Japanese plums, a Chinese apricot, and a purple-leaved plum from Persia. The work with the western Sand Cherry (*Prunus Besseyi*) is reported in Bulletin 87. Progress is also being made in originating hardy cherries, strawberries, and raspberries. By far the most extended experiment on record in the making of graft-hybrids of the apple has been undertaken, and we await the fruiting of the resulting plants with interest. In ornamentals the main work done has been crossing the wild Dakota and Siberian roses with choice double roses. If sufficient greenhouse facilities are afforded, the propagation of such new seedlings as give promise of permanent value will be pushed, so that they may be distributed for trial elsewhere as rapidly as possible. The advancing northward at least five hundred miles of the successful cultivation of the cherry, peach, and apricot, and that of winter apples, we trust will be some of the results of erecting this novel workshop for the invention of new hardy fruits.

Considerable success has been secured in hastening the fruiting of cross-bred seedlings. For instance, strawberries originated one winter by crossing the wild with the tame have been raised up to fruiting size the same year outdoors and fruited in pots under glass the following winter. This saves much time in selecting varieties for propagation, and also hastens the work of propagation by our being able to pot many layers before transplanting to the field.

In handling a quarter of a million fruit seedlings, I find many interesting side lines of investigation presenting themselves, but just now the main effort must be to originate a few varieties of the various orchard and small fruits worthy of a permanent place on the present limited fruit list of the prairie Northwest.

In handling so many thousands of seedlings, my endeavor in recent years has been to get some clew to the quality of the fruit while the plants are yet small. It would greatly lessen the labor involved. No positive correlations of this kind have as yet appeared. However, the two essentials of vigor and perfect hardiness are insisted upon from the beginning. With the sand cherry, of which I have a patch of over twenty-five thousand plants of the third generation under cultivation coming into bearing in the year 1905, I have found some seedlings that are quite free from mildew which so commonly affects the plant, especially in moist seasons. It is my belief that we can breed a mildew-resistant race of this promising prairie fruit. In a patch of over six thousand native plum seedlings I insisted on, as far as possible, perfect foliage as well as fruit of large size and good quality. In a patch of over three acres of strawberries of half-wild, half-tame ancestry, I insist on the leaves being free from rust (Ramularia), but it may be impracticable to do this wholly as our wild strawberries have the foliage affected in this manner. Whether we get our blight-proof apple remains to be seen. Any plant that will not endure forty degrees below zero with the ground bare of snow and come out unharmed the next spring is rejected. In disease resistance some peculiar facts crop out. For example, some pure wild roses mildew, while their hybrids with cultivated roses are free.

I have learned to look upon a species of plants only as a bundle of characteristics, more or less definite in its make-up, to be modified to suit our needs. A new seedling is really a new *invention.* Although legally "a gift of God," it is the result of the creative forces of nature under the guiding hand of man. Part of our labor is to improve nature's handiwork the better to adapt them to the needs of a civilization ever growing more complex.

Cornell Timothy-breeding.

By Samuel Fraser.

The prosperity of a good part of the country rests directly on grass. Timothy grass is the most important single crop in New York State. Yet we have no varieties of timothy, as there are of wheat and corn and beans. No good farmer would sow wheat without knowing the variety, for varieties differ in yield, hardiness, quality of grain, or other excellences. The experiment station of Svalof, Norway, has shown that the yield of timothy, for hay, may be considerably increased

FIG. G. — Cornell timothy investigation. Each clump is a single plant.

FIG. H. — Two seedling timothy plants, growing side by side, showing a common kind and degree of difference.

by the selection of varieties. It is to be expected that plants possessing other permanent characters

FIG. I. — Variation in heads of timothy.

of economic value may be found, and that we may secure some varieties which will be early in bloom and others which will mature later ; some possessing strong and long stolons and practically no corm, and therefore adapted to withstand grazing; and still others which produce abundance of fall feed.

A careful study of timothy will show that it is not all alike. It varies greatly; it is reasonable to expect that some of these variations are hereditable, and that this hereditability can be intensified or "fixed." In order to test these points, an experiment was begun in 1903. Timothy seed was secured from 230 sources in this country and abroad. With some selections made from individual plants on the University farm, 12,600 plants were set in the fall of 1903 in 300 plats. During 1904 and 1905 the planting of progeny, selected for various characteristics, has increased the number of plats to about 450, with 20,000 individuals. These, with a grass garden in which there are 6000 individual plants of about 50 species, many being the progeny of selected plants, cover about 10 acres of ground. There are 20 miles of rows of timothy plants. More than 100,000 distinct records have been recorded in a single year on 9000 of these plants.

All plats contain 42 plants, 30 inches asunder in rows 30 inches wide and in 2 rows of 21 each.

Every third plat is sown with a standard and uniform lot of seed grown on the University farm, and in 1905 all new check plats were sown with seed from one plant. The check plats measure any variation in soil conditions, and each

FIG. J.—A timothy plant that runs almost wholly to leaf.

variety or sample is measured by the yield or stand of the check plat alongside.

Example : —

Plats.	1	2	3	4	5	6	7	8	9	10
	c			*c*			*c*			*c*

It was soon apparent that the widest variations would be developed in the plants. These variations are of the following kinds: —

(*a*) In duration: some annual, others perennial;

(*b*) In stooling power: some ten heads, others two hundred and fifty; some have longer stolons than others;

(*c*) In time and manner of bloom: some a week or ten days earlier than others;

(*d*) In character of leaf: some are long, others short; broad, narrow; smooth, rough; erect, spreading;

(*e*) In shape and size of head and seed-production: large, thick heads can carry plenty of seed; some plants that promised well for pasture had very poor heads and little seed;

(*f*) In character of culm: some erect, others spreading;

(*g*) In general time of maturity: some develop early and by August will have a second lot of heads in bloom; others will not;

(*h*) In character of inflorescence: panicled and not;

(*i*) In vigor: in 1904, out of 9114 plants set in fall of 1903 from American-grown seed, 37 per cent were dead in 8 months, and 40.5 per cent in the first year. By 1905, or nearly 2 years after planting, 49.4 per cent had succumbed.

(*j*) In yield: in 1904, of the 5619 survivors above-mentioned, 103 yielded between ¼ and ½

FIG. K.—A timothy plant that runs much to seed.

pound hay and 3 yielded half a pound; 5500 yielded less than $\frac{1}{4}$ pound. In 1905, of the 4612 survivors, 4 yielded over $1\frac{1}{4}$ pounds of hay and 48 over one pound.

In Figs. H to L are shown some of the kinds of variation or differences in timothy plants.

Of course, nearly all the plants turned out to have no superior merits. In 1905, plants had been grown from seeds of ninety-three selected plants and three varieties were secured — enough for ninety-six plats. The characters were such as: heavy yield, poor yield; coarse stem, fine stem; early in bloom, late in bloom; thin heads, thick heads; broad leaves, narrow leaves; tall; leafy, not leafy; etc. All of these plats are checked by having a check plat beside them. All check plats are sown with seed from one plant, No. 9.03, the heaviest yielding plant having two years' record. In addition, centgener plats (containing one hundred plants placed in ten rows of ten each, six inches apart) were set from the thirteen heaviest-yielding plants. These are checked with No. 9.03 plants and have five foot alleyways between, to permit of covering the plat with canvas to prevent cross-pollination. Thus far the progeny from three heavy-yielding plants selected in 1904 have transmitted heavy-yielding characters, and the progeny of weak plants are weak and small in size.

FIG. L. — A productive timothy plant.

IV. UNITED STATES DEPARTMENT OF AGRICULTURE.

Probably the largest organized governmental plant-breeding enterprise in the world is in the United States Department of Agriculture. The "Laboratory of Plant-Breeding" is in charge of Dr. H. J. Webber, himself an expert breeder. Aside from the cotton-breeding, citrus-breeding, and other investigations by Dr. Webber, the following work was going forward in 1905: —

Alkali and Arid Plant-Breeding, Thos. H. Kearney and L. L. Harter.
Tobacco-Breeding, A. D. Shamel, W. W. Cobey, and Dr. W. W. Garner.
Corn-Breeding, C. P. Hartley and E. B. Brown.
Cotton-Breeding, Dr. D. N. Shoemaker, Prof. D. A. Saunders, E. B. Boykin, Prof. A. W. Bennett, Prof. S. M. Bain, and H. A. Allard.
Oat- and Potato-Breeding, J. B. Norton.
Wheat-Breeding, M. A. Carleton.
Breeding of Disease-resistant Cottons, Watermelons, Cow peas, etc., W. A. Orton.
Sugar-Beet-Breeding, Dr. C. O. Townsend.

Aside from the above principal lines of work, investigations are being conducted by the Department in the breeding of carnations, roses, dahlias, lettuce, apples, pears, and other plants.

In order to explain the point of view and to exhibit the methods of the work of this laboratory, I have secured from Dr. Webber and Mr. Carleton brief summaries of some of the pieces of work; and these statements comprise the remainder of this chapter.

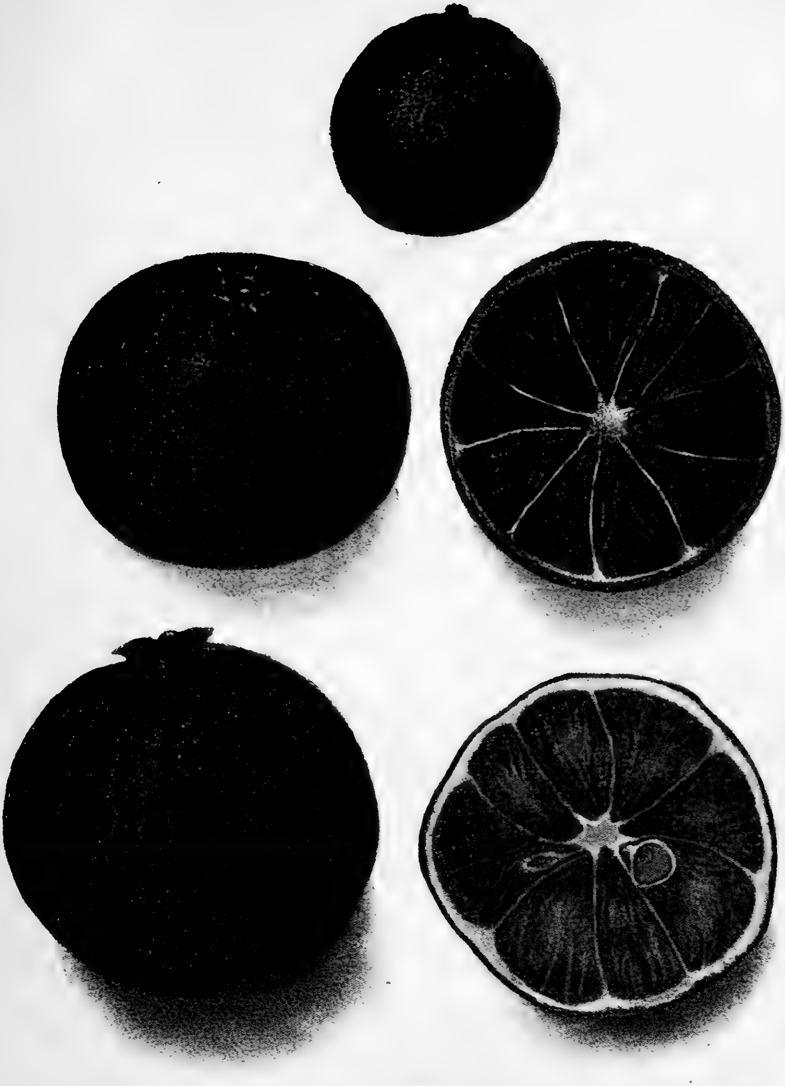


FIG. M. — Citranges (Hybrids of orange and *Citrus trifoliata*). Top fruit *Citrus trifoliata*. Top pair, Rusk Citrange. Bottom pair, Willits Citrange. ¾ nat. size. Reduced from colored figures in Yearbook of the Department of Agriculture.

Citrus-breeding.

By HERBERT J. WEBBER.

Work on the production of frost-proof types was started first in 1893–1894, but the hybrids were lost by accident; other hybrids were made in 1896 and 1897. A study of the possibilities in this direction indicated clearly that if any great advance was to be made, it would probably come through hybridization. For very many years, growers had been carefully watching for hardy variations, and among the many thousands of seedlings grown in Florida and other countries where freezes occur occasionally, such hardy variations, if there were any, would have been noticed and utilized. The Department sought to produce hardy types by combining the hardy but worthless trifoliata orange (*Citrus trifoliata*) with the common sweet orange, hoping to secure hybrids having the hardiness of the trifoliata and the edible fruits of the common orange.

The hybrids were found to vary greatly in the first generation, all that have thus far fruited producing markedly different types of fruit. The majority of these, as would be expected, have produced worthless sorts. The two sorts crossed were very distinct species and it was expected that a second generation of the hybrids would have to be obtained in order to secure the necessary variations; fortunately, however, the variation in the first generation was sufficient to give opportunity for selection. Three hybrid seedlings have already fruited which produce fruits of undoubted value, and these have been named and distributed to growers. These three new hardy fruits form a distinct new class of citrus fruits, and have been named *Citranges* (Fig. M). The three varieties or clons have been named respectively the Rusk, Willits, and Morton. The Rusk, which is a hybrid of orange ♀ × trifoliata ♂, is a beautiful little fruit resembling a tangerine orange in color and appearance, being nearly round and reaching a maximum diameter of about two inches. It is nearly seedless, averaging about one seed to two fruits. The pulp is exceptionally juicy and rather sour to eat out of hand without sugar. It is slightly bitter but not more so than the pomelo; with sugar it is a refreshing fruit to eat out of hand. It makes a very delightful citrangeade, a good pie, and excellent marmalade and preserves. For the latter uses it may ultimately be grown extensively.

The Willits, which is a hybrid of trifoliata ♀ × orange ♂, is very similar to a lemon, though differing in appearance. It has a rough, ribbed surface, but nevertheless a fairly thin skin and is very juicy. In cross-section it resembles the finest lemons. The fruits of the Willits make an excellent citrangeade of high quality and can be used for culinary purposes when the lemon is now used. Served with fish or ice tea, they will not be distinguished from the lemon unless well known to the eater.

The Morton, which is a hybrid of trifoliata ♀ × orange ♂, produces a fruit as large as the ordinary orange, and so similar in appearance to the orange that it can hardly be distinguished as a distinct fruit. It is almost totally seedless and is sweeter and less bitter than either the Rusk or the Willits. With sugar this variety is a very fair dessert fruit and is to be recommended mainly for use as a breakfast fruit. It is very near to a sweet orange.

Young trees of these three fruits have endured a temperature of eight degrees above zero, and it is believed that by slight protection for one or two winters, while the trees are young, they may be grown throughout South Carolina, Georgia, Alabama, Mississippi, Louisiana, in the greater part of Texas, in southern Tennessee and Arkansas, and in regions of low altitude in New Mexico, Arizona, Oregon, Washington, and northern California. In none of the above regions, except southern Louisiana and Arizona, can the ordinary orange be successfully grown. The citrange will thus extend the region of citrus culture about four hundred miles north of the present citrus belt.

The Production of New and Odd Types. — There is a continuous demand for new and odd varieties of citrus fruits and crosses were made of many different types of fruits. Hybrids of the tangerine and pomelo have given rise to a new group of fruits which has been designated the *Tangelo*. One variety of tangelo has already been named the Sampson (Fig. N), and another still under test will probably be named and distributed next year. The tangelo produces a fruit intermediate between the tangerine and pomelo, having the loose, "kid-glove" skin of the tangerine. It is sweeter than the pomelo, but more sprightly acid than the tangerine. The characteristic bitter flavor of the pomelo is considerably reduced but remains as a pleasant suggestion of that popular fruit. Withal the tangelo is an excellent dessert fruit and an interesting and valuable acquisition.

Two new tangerines, the Weshart and Trimble, resulting from a hybrid of Dancy Tangerine with Parson Brown Orange, have been named and distributed. While resulting from carefully hand-crossed seed, these fruits are strictly tangerines in all qualities. They differ from the ordinary varieties in being larger and about two weeks earlier in season — two characters of value.

A good blood orange has resulted from a cross of ordinary orange with pomelo, neither parent showing in any degree the "blood" character.

Two new limes have been named, which resulted

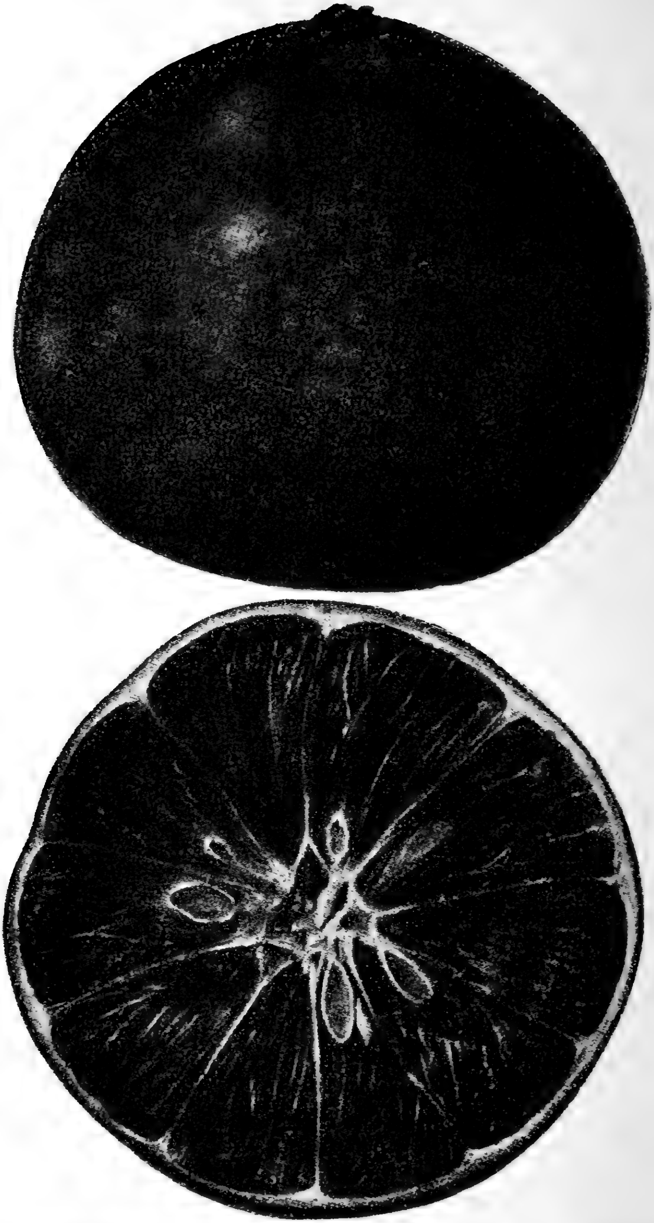


Fig. N. — Sampson tangelo. $\frac{5}{8}$ nat. size. Adapted from Yearbook.

from carefully hybridized seed of West Indian lime ♀ with the Sicily lemon ♂. Both are true limes in every noticeable quality, one producing a small fruit and the other a large fruit. Only a small number of the hybrids under test have yet fruited, and many more interesting new sorts will doubtless be obtained.

Pineapple-breeding.

By Herbert J. Webber.

The common market pineapple is ordinarily entirely seedless. So rarely are seeds formed that few people even among the growers have ever seen them. By hand-crossing different varieties it was found possible to secure a fairly large proportion of perfect seeds. From crosses of different varieties made by the writer in conjunction with Mr. W. T. Swingle, about three hundred hybrid seedlings were obtained. From such a small number of seedlings ordinarily very little of value would be expected to result. As a matter of fact, nearly twenty of these seedlings are quite different from existing varieties and seem to possess sufficient merit to justify their being named and distributed. The exceptional good quality and flavor of the hybrids as a whole is very noteworthy. It would seem as though the quality of the ordinary varieties must have deteriorated under long vegetative propagation and require the rejuvenescence of cross-fertilization to restore their good qualities. Unless some such explanation be true, it is difficult to understand the uniformly superior quality and flavor of the hybrids. Only one smooth-leaved variety is now cultivated in this country, the Smooth Cayenne, and this was crossed with various sorts with the hope of producing more smooth-leaved varieties. Such hybrids have furnished a number of promising smooth-leaved varieties. It is interesting to note, however, that almost as many smooth-leaved seedlings resulted from crossing spiny leaved sorts as resulted when the Smooth Cayenne was used as one parent. Five of these hybrid seedlings which have been fruiting since 1901 will be described in the 1905 Yearbook of the Department of Agriculture.

Cotton-breeding.

By Herbert J. Webber.

Production of Long-staple Upland Races.

The cotton-breeding work of the Department was started in 1899, when the writer first took up the problem of creating better-yielding, long-staple races. There is a growing demand for long-staple cotton, and the regions where the long fibre can be profitably cultivated are very limited. The short-staple sorts, having fibre usually from seven eighths to one and one-sixteenth inches in length, are grown all over the great cotton belt of the United States. Of this cotton we produced last year (1904) over thirteen million 500-pound bales, while the maximum production of long-staple upland sorts, grown principally in the rich bottom lands of Mississippi and Louisiana, has never exceeded about two hundred thousand bales per annum. The long-staple upland cottons produce fibre ranging from one and one-fourth to one and one-half inches in length, and usually sell from twelve to eighteen cents per pound when ordinary cotton is selling at nine and ten cents. The longer the fibre the better and stronger the yarn produced, and the better the goods manufactured. If, then, we can secure one and one-fourth to one and one-half inch staple cotton that will equal in yield the ordinary upland cotton on the same soils, the longer-stapled sorts should ultimately supplant the short-staples.

It seemed to the writer that the most feasible way of producing such long-staple sorts adapted to upland regions was to hybridize the very long-staple sea-island cotton (*Gossypium Barbadense*) with the short-staple upland sorts (*Gossypium hirsutum*) and select the hybrids in an upland cotton region, the aim in such an experiment being to combine the fine, long, and strong lint qualities of the sea-island cotton with the large,

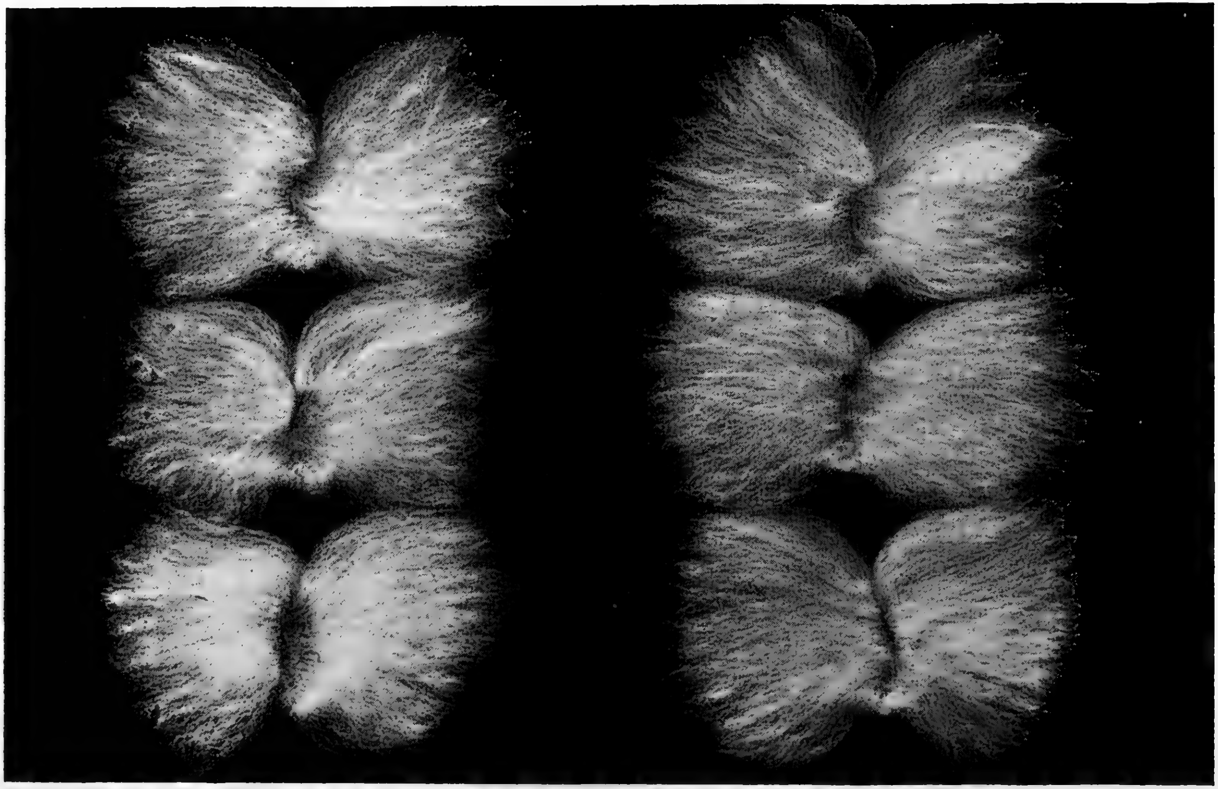


FIG. O. — Pride of Georgia, a good short-staple cotton. Natural size.

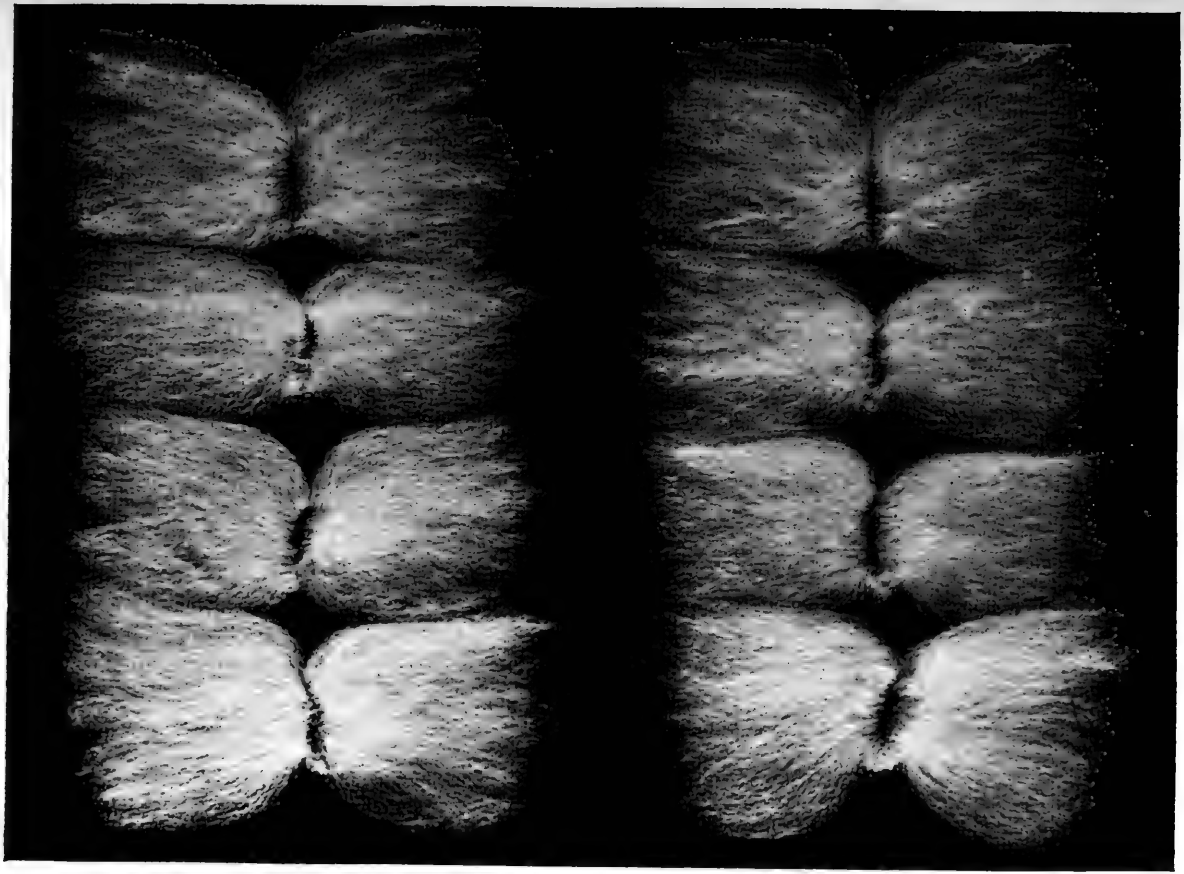


FIG. P. — Select Jones Improved cotton with uniform long staple (lint 1⅜ in. long). Somewhat reduced.

round, easy-picking bolls, greater productiveness, and adaptability to upland conditions of the upland short-staple cotton. Another feature that seemed important to the writer was to get in the hybrid varieties, the smooth black seed of the sea-island instead of the fuzzy seed of the upland, so that roller gins could be used in ginning the cotton, if found desirable. Throughout the work these ideals have been kept closely in mind, and every plant examined carefully, and those selected, carefully graded.

In 1899 a number of hybrids were made and the first generation was grown in 1900. These were examined and the most promising bred *inter se.* In 1901 six acres of second-generation hybrids were grown, thus giving many thousand plants to select from. In this generation twelve specially good plants possessing the desired combination of characters were selected and each of these were planted in isolated acre patches in 1902. A large number of other plants were also selected and grown together in a miscellaneous patch the next year. In 1902 the progeny of each of these acre patches was carefully watched, and every undesirable type pulled out as soon as discovered, reducing the number of plants in each acre to about twenty-five or thirty. These were used to plant the same isolated patch the next season (1903). This process, coupled with careful grading, has been continued every year since. By the fifth generation (1904) the twelve types had been reduced to five, and these had reached a stage of fixity as complete as is found in the majority of cotton races; they yet produced a good many plants with fuzzy seeds and some with short lint. This year (1905, in the sixth generation) one of the varieties has reached sufficient fixity and is of such promise that it is thought to be ready for introduction into cultivation as soon as it can be propagated in quantity. Considerable roguing will be necessary to keep it up to a high state of production and quality. Two other of the hybrid types are also nearly fixed and will certainly be valuable sorts. One of these hybrids, it is believed, will give lint nearly equal to the fine sea-island in length, strength, and fineness. The lint, however, is produced on a typical upland cotton plant with large, round bolls. The fields of these cottons this year at Columbia, S.C., are equal to the best uplands in the vicinity, where unselect seed has been used. (Figs. O and P show short-staple and long-staple cottons.)

The greatest surprise in our work has come through experiments in the improvement of the lint by the straight selection of certain big-boll uplands. A three-year selection from Jones Improved ordinarily having lint averaging one inch, and not over one and one-eighth, has given us this year a field of seven acres averaging about one and one-fourth inches, and several progenies from selection of last year averaged one and three-eighths inches of fine, long, strong cotton. It is exceedingly promising and will be grown for distribution next year. These plants have been carefully selected, the pedigree running back to carefully selected individuals three generations ago.

A straight selection of Russell Big Boll now in fourth generation of selection is also showing the same marvellous increase in lint length without reduction of its productiveness. If these cottons will hold up three years after selection ceases, they should drive short staples out of the market ultimately. I believe that the continuation of the selection will render the character practically fixed until reduced by intermixing.

We have a pedigreed strain of a short-staple variety, Pride of Georgia, which has this year and last given a very much better yield than ordinary cotton. We expect to send seed of this to about three thousand planters this winter (1905-6).

Many other selections and hybrids are under experimentation, some of which will doubtless prove valuable.

Wheat-breeding.

By M. A. Carleton.

In the wheat-breeding experiments of the United States Department of Agriculture there are about 950 wheat hybrids, selected from 286 original crosses. The accompanying illustrations (Figs. Q–T) are very good examples, showing some of the most interesting variations. A brief description is given of the methods of operation, followed by some notes on results.

Method of Work.

A very large part of the work of improving wheat is simply the selection each year of better plants and the occasional introduction of distinct varieties from foreign countries that are better adapted to the particular conditions under which the crop is to be grown. We have found, indeed, that if this kind of work is conducted thoroughly, with a broad knowledge of wheat varieties and their adaptation, the results of hybridization are made much more effective and, especially, very much time is saved. We are obliged to infer from previous experience that much work in wheat-breeding has been done needlessly because of the lack of previous knowledge of varieties, which knowledge would have shown that there already exist certain varieties much better than those obtained through cross-fertilization. To illustrate, if one wishes to secure varieties more resistant to rust, there will be a saving of both time and labor by securing first the variety best in this regard among those already in cultivation. Such varieties as are best with respect to any one quality are often found in foreign countries.

The best varieties, so far as we know them, having been established by thorough adaptation tests, are used from which to select the best plants for use in cross-breeding. Suppose we wish to improve the wheat of the Middle West, generally represented by the Crimean or Turkey winter wheat, by giving it greater rust resistance. The best plant of the Crimean as to yield, hardiness, and quality of grain is selected and crossed with the best plant of a variety of the durum wheat group, the Velvet Don, for example, which has the quality of rust resistance to an exceptional degree. This latter variety is also very resistant to drought. We hope, therefore, to secure from the progeny a new variety having all the good qualities of these two parents, and will try, as far as possible, to eliminate the bad qualities. The good qualities are yield, winter hardiness, excellence of kernel for bread-making, rust resistance, and resistance to drought.

The parent plants having been selected, it will depend on the circumstances of flowering as to which one will be chosen as the female parent.

The Velvet Don being for most regions a spring variety, it would be chosen in this case for the female parent, as its time of flowering would be a little later than that of the Crimean, and we can therefore be more certain that it has not been self-fertilized.

The operation of artificial cross-pollination is about as follows: The articles provided for the work are, a small pair of forceps, such as used in ordinary laboratory work, a small pair of curved scissors (similar to manicure scissors), and a supply of very small white tags with strings attached ready for use. With the forceps the glumes of the flower to be cross-pollinated are spread apart and the three stamens taken out bodily, thus completely emasculating the flower if the operation has been done at the proper time, just before the anthers are ripe.

The same day or the next morning, pollen is taken from the fully ripened flowers of the plant selected for the male parent and scattered within the opened glumes of the flowers that were emasculated as above described, after which the glumes are smoothed back into their former positions as nearly as possible. There appears to be much variation in the practice of different persons as to the number of flowers pollinated. On an average, we cross-pollinate about sixteen flowers in each head operated on, these being the eight outside flowers of the four best spikelets on each side of the head. The spikelets are chosen just above the middle of the head, that is, a little nearer to the apex than to the base. In all cases where there are more than two flowers to each spikelet, the middle one and any others that may be present are also emasculated, but not pollinated, the outside flowers usually producing a little the best grains. The spikelet immediately above those that are pollinated and the one immediately below are nipped with the scissors, which mark indicates that the operation has been made on the spikelets between. After the operation is performed, one of the white tags is tied to the stalk and the names of the parents and the date of the cross written upon it. So far as can be determined, the best head of the plant is pollinated, but sometimes two or three heads of the same plant are employed. After trying the experiment for some time, the practice of tying paper or cloth bags over the cross-pollinated heads has been abandoned. Often the head is much injured by the operation, particularly in times of wet weather, and there does not seem to be much need of it. After some experience one can determine very readily whether there has been any natural cross-pollination other than the one intended simply from the nature of the results, and really such an instance seems never to have occurred in our experience. In this connection it is worth while to remark that one becomes able after a while to determine rather accurately what parents were employed in any particular cross merely by the characters of the progeny.

At first there are likely to be many failures in the production of kernels from these cross-pollinations, but after considerable experience ordinarily good work will result in an average production of kernels from about sixty per cent of the crosses. One great mistake often made, and one that was made by ourselves at the beginning of our work, is that of cross-pollinating too small a number of flowers. Instead of eight or a dozen cross-pollinations, there ought to be more nearly one hundred in the case of every cross. It may be necessary to secure a great many variations and to have a large number of progeny before there is obtained the particular variation that one desires. In all our operations now, we are attempting to produce in every case just as many cross-pollinated kernels as possible up to the limit of about one hundred, but we always expect later to discard scores of plants from the progeny. It is only by having a large number of individuals to work on and by a process of rigid elimination that we are able to secure the best results.

Another way by which a number of undesirable plants are eliminated, particularly in the winter-wheat region, is the practice of planting the kernels produced from these cross-pollinations in exactly the same way and under the same conditions as the ordinary standard wheats are planted. It is not the practice in our work to give any special care to these new plants. Therefore, only the hardiest survive, and in some cases as small a number as ten per cent of the entire number planted has survived the winter. The method of planting the seeds of our hybrids, as well as the standard varieties of all the cereals, is to sow them in drill rows about fifteen inches apart. In the cases of the standard varieties, the furrow is first made and then the seed sown by a hand drill in the furrow thus prepared. Of course in the cases of the hybrids the seed must be sown by hand. Later on, in order that the hybrids may be grown under ordinary field conditions and yet that statistical results from the progeny may be obtained, the seeding of each one is duplicated in two ways: that is, a small part of the seed is sown, a kernel, in a place about six inches apart, in a row twenty feet long, the remainder of the seed being sown with a hand drill just as the standard wheats are planted.

The work requiring the most care is the after-treatment and selection of these hybrid wheats. As stated, scores, and later on hundreds, of individual plants from the progeny of each hybrid are discarded every year; but of course it requires constant study and rather critical judgment to determine whether it is wise to discard a plant or not. Also, because our experimental stations are at a number of different points throughout the country, it is often true that a line of variation in the progeny, though found to be ill adapted to a certain locality, may be very nearly just what is wanted in some other district. Some of the most interesting work is that of the separation of the progeny of these hybrids into classes, based on the lines of variation having qualities suited for different purposes or regions.

A complete pedigree record is kept of all the progeny of the original hybrid, and later, when the new varieties that have been developed along certain lines of variation become fixed, a summary of the statistical results shown in the notes on these progeny is made out on large sheets. Detailed notes on the characteristics of the individual plants are recorded in a field note-book made of a size conveniently to fit the coat pocket. In the case of the standard varieties, they are all entered in this note-book according to accession number, a list of the varieties corresponding to the numbers being placed in the back part of the book for reference when needed. After the column of numbers there are many other columns in which there is given opposite to each number the notes on height of plant, time of ripening, rust resistance, size and shape of heads, character of the kernels, etc. After fixation, each hybrid is given an accession number and treated the same as a standard variety. Before fixation, and while the variations among the progeny are under observation, the different variations are indicated by a special system of numbering, which is the same as that used also by Dr. H. J. Webber and his assistants in other plant-breeding work and which is as follows: The hypothetical cross of Velvet Don with the Crimean above mentioned, supposing the number of the cross to be twenty-three, would be indicated as follows, if the hybrid has been carried through the fifth generation, which is true now with nearly all of our hybrids: 23a 2-1-3-1-2. This number attached to a plant indicates that it is the second selection of plants of the fifth generation of the hybrid No. 23 Velvet Don × Crimean. After the first number, which is the number of the original cross, every figure indicates a generation, and therefore the number of figures show at once the number of generations in the cross. In this case the progeny has descended from the plant produced by the second grain in the cross, No. 23a. From the seed of that plant a number of individuals are produced in the second generation, of which No. 1 was selected for this line of variation. In the third generation No. 3 was selected. In the fourth generation No. 1 was selected, and in the fifth, No. 2. The letter following after the cross number, which is *a* in this case coming just after No. 23, indicates which cross is referred to as regards the individual parent plants; that is, there might be another cross made of Velvet Don with Crimean, but in that case it would be No. 23b, and if there were a third one it would be No. 23c, the particular parent plants being different in the cases of *b* and *c*. In taking field notes on the hybrids, this number, 23a 2-1-3-1-2, is placed in the proper column instead of the accession number, as in the case of the standard varieties.

Results.

Although we have experimented with many hybrids, it is desirable, for the purpose of condensation, to illustrate the results simply in a general way by a description of a few of the most representative cases. The accompanying photographs illustrate four of the hybrids here described, all the pictures being similarly reduced in size. Although the hybrids have been carried through five generations, it is impossible, without much further work, to discuss here the variations farther than the third generation. However, this includes the most interesting periods, there being very few changes that are of interest in the later generations.

In some cases it would be desirable to show the kernels, but in most instances these are not available and at any rate could not very well be shown in a photograph. In mentioning a hybrid, the name of the female parent is given first, then the sign ×, followed by the name of the male parent. In the accompanying photographs the parents are shown at the left of the sheet, the first one being the female parent.

Special Notes on Certain Crosses.

I. *Hybrid Yx* × 1344. — Yx, the female parent, is a hardy, red-chaffed, red-grained, bearded winter variety, and 1344 is a white velvet-chaffed variety with rather soft grains and no beards. In the second generation, plants with both red-chaffed and white-chaffed heads appear, the most interesting and valuable of which are those having large, vigorous heads with red chaff, the size and vigor coming from the male parent and the hardy characteristics and good quality of the grain from the variety Yx.

II. In a cross of Ghirka Winter × 1392, there is introduced the interesting feature of a bearded club wheat in the second parent. In the first generation, one plant is clubbed but has no beards. In the second generation there are two individuals with clubbed heads and no beards, and one other with clubbed heads and beards. The parent 1392, coming originally from north central Asia, is characterized by early maturity, and this characteristic appears in several of the progeny. Earliness in a plant something like No. 1 or 2 of the second generation (see illustration) would be very important from an economical standpoint. Ghirka Winter is a very hardy winter variety with hard, red grains, white chaff, and no beards. (Fig. Q.)

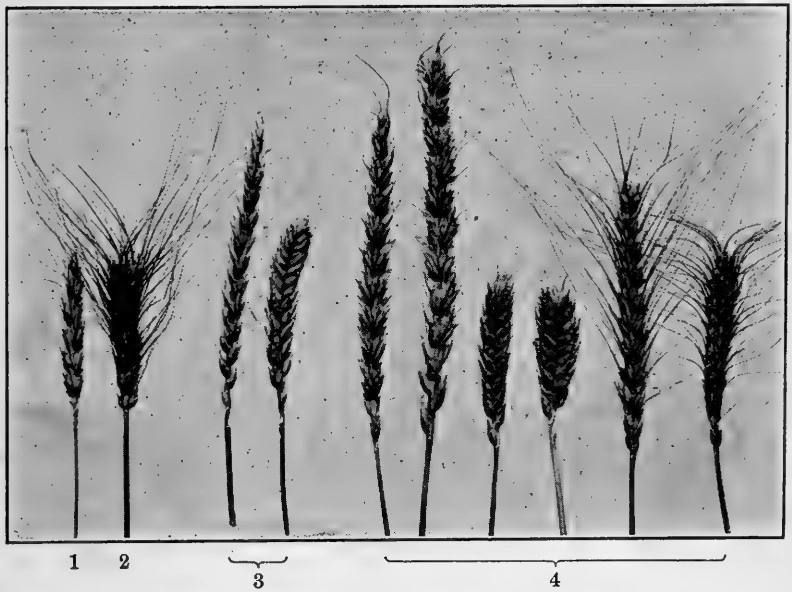


FIG. Q. — Ghirka Winter × 1392. 1. Female parent. 2. Male parent. 3. First generation. 4. Second generation.

III. One of the interesting crosses is that of Arnautka × 1403. Arnautka is the native durum wheat of the Northwestern States; that is, it has been grown there in a small way for a quarter of a century, having come originally from Russia. The 1403 is also a durum variety, but differs from the Arnautka in having a velvet chaff. In this cross there is an unusual and interesting feature of a true club wheat appearing in the second generation which is also bearded. Neither of the parents is known to be a hybrid, so it is not likely that this plant could be a reversion to an older ancestor.

IV. *Ghirka Winter* × *Spelt*. In this cross there is introduced as the male variety a representative of a distinct group of wheats, the true spelt. These wheats are not grown at present in this country except at the experiment stations, although the name is often incorrectly applied to emmer. The parent, Ghirka Winter, has already been described. The spelts have long, slender heads with usually only two grains in a spikelet and the spikelets arranged far apart, producing a very loose head. For the first generation of this cross, only one plant is represented in the illustration, and this is in all essential features like the male parent. In the second generation some of the progeny approach the male parent by different degrees, Nos. 3 and 5 (see illustration) being very much like it. The spelts are very constant in fertility, every flower almost always producing a grain, and this characteristic, if transmitted to the offspring of a cross, is of economic value. They also have a very tenacious chaff. Nos. 2 and 4 are likely to be of the greatest economic value, having to some extent the good qualities of both parents. (Fig. R.)

Fig. R. — Ghirka Winter × Spelt. 1. Female parent. 2. Male parent. 3. First generation. 4. Second generation.

V. In the cross of Diehl Mediterranean × Jones's Winter Fife, there are illustrated variations to the third generation. The female parent is a red-chaffed, bearded wheat without velvet. The male parent, Jones's Winter Fife, is a beardless, white, velvet-chaffed wheat. In the third generation it will be seen that there is quite a range of variation, although all of the plants were produced from the single plant here shown of the second generation. (Fig. S.)

VI. *Jones's Winter Fife × Ufa emmer.* In this cross several very interesting things are shown. One soon finds that the emmers stamp their characteristics very emphatically upon the offspring in any cross in which they occur. At the same time Jones's Winter Fife is itself a very vigorous hybrid with a long pedigree, and is also quite pre-potent. In the first generation, No. 1 (see illustration), is very much like the female parent, Jones's Winter Fife, having even the

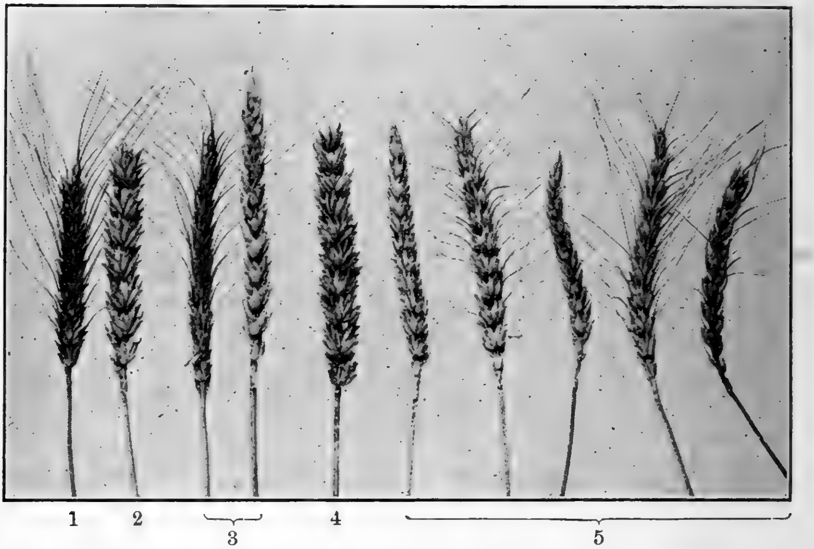


Fig. S.—Diehl Mediterranean × Jones's Winter Fife. 1. Female parent. 2. Male parent. 3. First generation. 4. Second generation. 5. Third generation; five plants, progeny of No. 4.

velvet chaff, which is a characteristic of that variety. No. 2, however, is a very striking example in which the characters of both parents are distinctly shown, having a head of exactly the shape of the emmer and at the same time a thick velvet characteristic of the female parent. In this plant, however, there are no beards. In the second generation there is a club wheat with velvet chaff, which, however, is not shown in this illustration. To one not familiar with the history of either parent this fact would be peculiar, especially as neither parent is a club, and plants with clubbed heads, so far as we know, would not appear in crosses of one of the common wheats with an emmer unless one of the parents is itself clubbed. In this case the explanation, no doubt, is that several of the ancestors of Jones's Winter Fife were club wheats, so that this is a reversion to the character of an older ancestor. Even the plant of the second generation here shown (see illustration) is slightly clubbed, but otherwise has the shape of head and the beards of the emmer and the velvet chaff of Jones's Winter Fife. From this plant were produced all the variations shown in the four plants of the third generation here illustrated. (Fig. T.)

VII. Finally, I would mention a cross of a red beardless spelt × Ufa emmer. The Ufa emmer is a rather hardy variety of this group, coming from extreme northeastern Russia near the Siberian border. In the progeny of this cross are a number of plants having heads very similar to those of our common wheats. The occurrence of these heads would indicate the possibility that a number of our common varieties well known to-day originated many years ago from crosses of the spelts and emmers either with each other or with varieties of other groups.

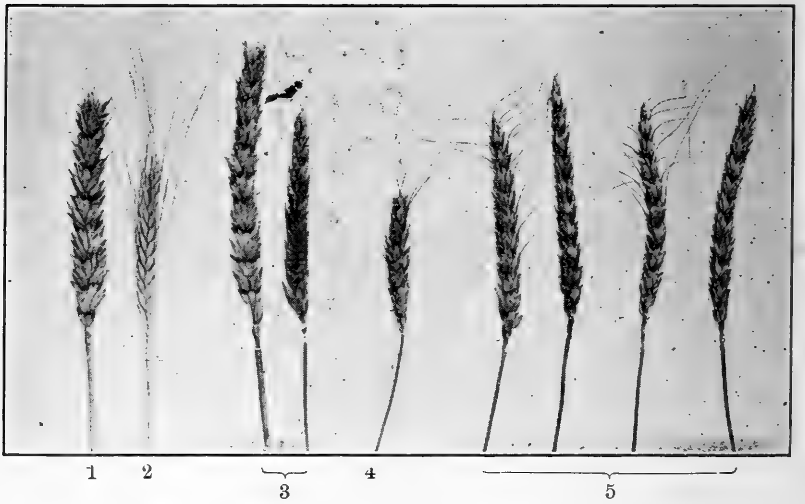


FIG. T. — Jones's Winter Fife × Ufa emmer. 1. Female parent. 2. Male parent. 3. First generation. 4. Second generation. 5. Third generation; four plants, progeny of No. 4.

General Remarks.

In our experiments we have succeeded in crossing all groups of wheats with the common varieties except the einkorn group, known botanically as *Triticum monococcum.* A number of attempts were made to cross with this group, but we are not certain so far that any one has succeeded. However, several crosses have been made with the Polish wheat, which certain writers have supposed could not be accomplished.

In all instances when a club wheat is one of the parents, there are striking variations, probably because of the fact that club varieties are almost always, or perhaps always, the direct result of a cross of two different wheat groups and not the result of a long series of selections. The hybrid would, therefore, naturally break up into many variations, showing a reversion to the characters of original ancestors.

In many cases when one or both of the parents is already a hybrid, there are reversions to characters of former ancestors which would be wholly inexplicable on any other basis than the fact that the parents themselves are hybrids.

A spelt or an emmer, when used as one of the parents, invariably fixes emphatically its characteristics upon the progeny.

It has been supposed that variations do not occur to any considerable extent in the first generation, but we have found some of our most striking variations appearing in this generation, particularly in the case of crosses with fixed hybrids or with the emmer and club groups.

Characters occasionally appear in the progeny which cannot be traced to either parent, and yet in cases in which neither parent is known to be a hybrid.

Pedigree Records used in the Plant-breeding Work of the Department of Agriculture.

By Herbert J. Webber.

In all of the work of breeding pursued by this office, the individual parents are followed in practically every case, unless it be pure selection work, where the following of the male parent is not very important. In all cases, however, the female parent is fully recorded and described.

Numbering the plants. — The records in each crop are kept separate. Under each crop there is maintained a continuous series of what is termed "Series Numbers," or "Experiment Numbers." For example, Series No. 1 may be hybrids of Constellation sea-island cotton, with pollen of Klondike Upland; and all of the hybrids of this combination are placed under Series No. 1. Series No. 2 may be hybrids of Truitt with pollen of Texas Wood cotton ; and all of the hybrids of this combination will be placed under Series 2. Series 3 may be a straight selection of Truitt, and all of the selections of Truitt made under a given condition are given the No. 3.

In the case of a hybrid, as in Series No. 1 mentioned, a certain boll on a given plant may be crossed with pollen from one individual, while another boll on the same plant may be crossed with pollen from a different individual. It is thus necessary in keeping the record of the hybrids to have a method of designating each individual fruit or boll crossed. The different crossed bolls in this case would be numbered 1 A, 1 B, to 1 Z. The letters of the alphabet are usually sufficient to cover the number of crosses made of a certain kind. When the progeny of these different bolls are grown and the first generation of hybrids are produced, these hybrids are numbered as follows: The hybrids produced from capsule 1 A are numbered 1 A 1, 1 A 2, 1 A 3, etc. Owing to the necessity of keeping the records within certain space, numbers are assigned only to those hybrids which are actually selected, so that in case of a large number of hybrids, only a few numbers would actually be preserved, although records would be preserved of the general variations in all of the hybrids produced.

When a second generation is grown from the above first generation of hybrids, the individuals of the second generation would be numbered as follows: Those grown from 1 A 1 would be numbered 1 A 1-1, 1 A 1-2, 1 A 1-3, etc., and those from 1 A 2 would be 1 A 2-1, 1 A 2-2, 1 A 2-3, etc.

This method illustrates the system of numbering all hybrids in the third, fourth, and succeeding generations, the members of the different generations being separated by a dash, as in the above instance, so that in the case of any combination a glance will show whether or not it is a hybrid and what generation the hybrid is in. In Series 2 before indicated, the numbering would be in accordance with the same rule, *i.e.* 2 A, 2 B, 2 C, etc., for the different crossed capsules, and 2 A 1, 2 A 2, 2 A 3, and 2 B 1, 2 B 2, 2 B 3, etc., for the individual hybrids of the first generation.

In the case of Series 3, which is a straight selection, there is not the necessity of using the letter, as the experiment starts with the selection of a certain number of individuals. The individuals which are first selected would thus be numbered 3-1, 3-2, 3-3, 3-4, etc., the first number being the number of the series and the second number the number of the individual plants first selected. When these selections are grown in a second generation, they are designated as follows: 3-1-1, 3-1-2, 3-1-3, and 3-2-1, 3-2-2, and 3-2-3, etc. It will be noticed by comparing Series 3 with Series 1 and 2 that the numbers used for selections differ only from those used for hybrids in leaving out the letter, which marks the individual capsules which are crossed in the case of Series 1. The use of this system of numbering allows the filing of record cards according to the series number and the number of the generation, so that they may be found with the greatest ease.

Blanks used in keeping records. — The records of all hybrids and selections are made on loose sheets, which are filed either in books or in a card-index case. A special sheet is expected to be used for the record of each plant which is selected. The sheet has a blank form for the description of the plant and for the description of the progeny which it produces. Plant-breeding Form No. 1 (sample on page 315) is the introductory sheet to a series of hybrids. All introductory sheets are of thick paper and blue in color. The introductory sheets for selections are of similar form and color (see sample, page 316). On these introductory sheets is to be put, in the case of the hybrids, the description of the female and male varieties, and the object of the hybridization. In the case of selections, the description of the parent variety and object of the selection are recorded, together with any general notes on the plants which are grown for the selection.

In the case of hybrids, a parental sheet is used, which corresponds to the letters used in designating the different crosses. On this salmon-colored sheet (see sample, page 317) is given the descriptions of the individual characters of the female parent and the individual characters of the male parent, together with notes on the general progeny grown from a certain boll or fruit. In the case of selections there is no parental sheet used as the different bolls and fruits are not kept separate. When the individuals are grown and notes made on them, individual white sheets are used, both in the case of selections and hybrids. One of these sheets for hybrids is illustrated in P. B. Form 3 (page 318), which is a blank that can be used with hybrids of any plants, and is not specially adapted to any particular crop. The same individual white sheet for selections is illustrated in P. B. Form 7 (page 319).

Whenever much work is to be done with a certain crop, it becomes necessary to have the blanks drawn up in the form of score cards, in order that the important characters of the breeding material may be scored according to a statistical method. Such cards for cotton hybrids are illustrated in P. B. Forms 4 (salmon) and 5a (white) and P. B. Forms 8 (blue) and 9a (white) for cotton selections. In all of the work a regular score card is used ; on page 328 is shown a blank yellow score card which is used in cotton-breeding work (P. B. Form 15). The valuation of the different points is filled in according to the particular ideal which the breeding is expected to develop.

The record sheets, as mentioned above, are the uniform size of nine and one-quarter inches long by seven inches in width, and may be filed in any loose file sheet. The best form which has been found for this purpose and the one which is used in the Department's work is the so-called "Perfect File," which holds the sheets firmly and at the same time allows of a single sheet being extracted at any point without disarranging the others.

A difficulty with the above plan has been found in the fact that the record sheets are too large to carry in the field, and more recently a small sheet of the standard size of six and one-half inches long by four inches wide has been used. These sheets are bound in note-books, so that they may be torn out and filed in card-index cases.

The different blank forms on the smaller sheets are arranged exactly the same as in the case of the larger ones described above. P. B. Forms 41, 42, and 46 show the general forms which are used in making the records in cotton selections (pages 330 to 332). Number 41 is white, 42 pink, and 46 blue. It will be seen on P. B. Form 41 (page 330) that the important characters which are to be judged are placed on a score card in the upper part of the sheet; as, for example, under "Season," if a plant is early, one would check the word "early"; and if a cotton which is early is scored on the basis of ten points the score record of probably eight points would be inserted on the blank just below "Season." In the space marked "Length of Lint," one would insert the exact measurement of the lint, as, for instance, one and one-quarter inches, and below this point in the score line insert the score value for this length of lint. These smaller sheets which are put up in pocket note-books are very much handier to use than the larger sheets; and so far as we can find, answer every purpose.

We are finding it necessary continuously to reduce the amount of notes taken, rather than increase them. One is inclined to get a large collection of notes, and if he is doing extensive work is never able to correlate or utilize them. One of the most important things for the breeder to do is to learn to limit the notes to the factors of importance, and avoid making notes or saving plants indiscriminately.

[The forms reproduced on pages 315 to 319 are necessarily shortened as to horizontal length in order to accommodate them on a single page.]

Hybrid.

Introductory
Sheet.

-------**Series No**.----.

Female Parent------------, U.S.P.B. No.----.
Male Parent--------------, U.S.P.B. No.----.
Notes----, page-----. Year-----.
Experimenter.--------------------.

P. B. Form 1.

Characters of Female Variety:

Characters of Male Variety:

Object of Hybridization:

Introductory hybrid record sheet. Blue. 9¼ × 7 in.
(P. B. Form 1.)

Selection.

Introductory
Sheet.

P. B. Form 6.

_______ **Series No.**____.

Parent Variety__________, U. S. P. B. No.____.

Notes____, page____. Year____.

Experimenter__________________.

Character of Parent Variety:

Object of the Selection:

Notes on Plants grown for Selection
(See Notes____, page____):

Introductory selection sheet. Blue. 9¼ × 7 in.
(P. B. Form 6.)

Hybrid.

Parental Sheet.

P. B. Form 2.

-------**Hybrids, Series No**.----.

FEMALE PARENT-----------, U. S. P. B. No.----.

MALE PARENT-------------, U. S. P. B. No.----.

Notes----, page----. Year----.

Experimenter--------------------.

Individual Characters of Female Parent:

Individual Characters of Male Parent:

Progeny Notes (See Notes----, page----):

Parental sheet. Salmon. 9¼ × 7 in. (P. B. Form 2.)

Hybrid.

Individual
Sheet.

P. B. Form 3.

-------**Hybrid No.**----.

PARENTAGE-------------♀, × -----------♂.

Inbred-----------. Year----.

Experimenter--------------------.

Field Notes (*See Notes*----, *page*----):

General Notes:

Progeny Notes (*See Notes*----, *page*----):

Individual hybrid sheet. White. $9\frac{1}{4} \times 7$ in. (P. B. Form 3.)

Selection.

Individual
Sheet.

-------**Selection No.**----.

PARENT VARIETY----------, U. S. P. B. No.----.

Inbred-----------. Year----.

Experimenter-------------------.

P. B. Form 7.

Field Notes (*See Notes*----, *page*----):

General Notes:

Progeny Notes (*See Notes*----, *page*----):

Individual selection sheet. White. 9¼ × 7 in. (P. B. Form 7.)

Cotton Hybrid.

Parental Sheet.

P. B. Form 4.

Cotton Hybrids, Series No.........

Female Parent.., U. S. P. B. No........

Male Parent.., U. S. P. B. No........

Notes........, page........ Year........ Experimenter........................

Individual Characters of Female Parent:

Individual Characters of Male Parent:

Progeny Notes (*See Notes*........, *page*........):

Locality Where Grown	Date Planted	Number Plants Grown	Number Plants Harvested.	Earliness	Height — Form of Plant	Disease Resistance	Size of Bolls	Opening of Bolls	Seed			Lint						Yield of Seed Cotton	Per cent of Lint	Total Score
									Size	Per cent Smooth	Per cent Tufted	Length	Color	Fineness	Uniformity	Strength	Drag			

Parental cotton hybrid sheet. Salmon. 9¼ × 7 in. (P. B. Form 4.)

Cotton Hybrid.

Individual Sheet.

P. B. Form 5 a.

Cotton Hybrid No..........

PARENTAGE .... ♀, × .... ♂.

Inbred .... Year .... Experimenter ....

Field Notes (*See Notes*........, *page*........):

General Notes:

Date Planted	First Bolls Opened — Earliness	Height — Form of Plant	Disease Resistance		Weight Ten Bolls Seed Cotton	Number of Bolls	BOLLS		SEED			LINT						Yield of Seed Cotton	Per cent of Lint	Total Score
							Size	Opening	Smooth or Tufted	Size by Weight	Covering	Length	Color	Fineness	Uniformity	Strength	Drag			

Progeny Notes (*See Notes*........, *page*........):

Locality Where Grown	Date Planted	Number Plants Grown	Number Plants Harvested.	Earliness	Height — Form of Plant	Disease Resistance	Size of Bolls	Opening of Bolls	SEED			LINT						Yield of Seed Cotton	Per cent of Lint	Total Score
									Size	Per cent Smooth	Per cent Tufted	Length	Color	Fineness	Uniformity	Strength	Drag			

Individual cotton hybrid sheet. White. $9\frac{1}{4} \times 7$ in. (P. B. Form 5 a.)

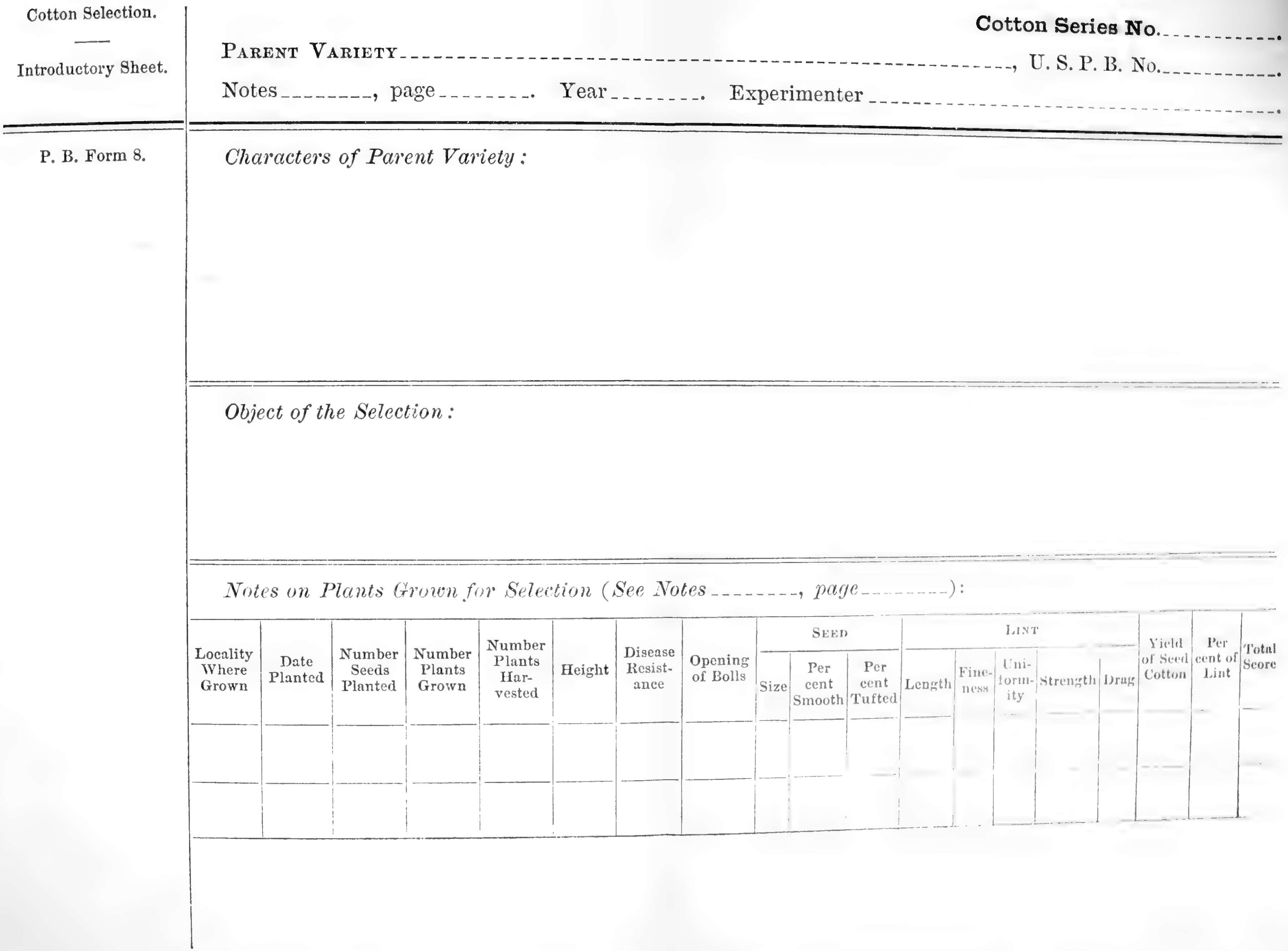
Cotton ----.

----.

Introdu

----.

P.



Cotton Selection.

Introductory Sheet.

P. B. Form 8.

Cotton Series No.__________

PARENT VARIETY____, U. S. P. B. No.__________

Notes________, page________. Year________. Experimenter ______________________________

Characters of Parent Variety:

Object of the Selection:

Notes on Plants Grown for Selection (See Notes________, page________):

Locality Where Grown	Date Planted	Number Seeds Planted	Number Plants Grown	Number Plants Harvested	Height	Disease Resistance	Opening of Bolls	SEED			LINT					Yield of Seed Cotton	Per cent of Lint	Total Score
								Size	Per cent Smooth	Per cent Tufted	Length	Fineness	Uniformity	Strength	Drag			

Introductory cotton selection sheet. Blue. 9¼ × 7 in. (P. B. Form 8.)

Cotton Selection.

Individual Sheet.

P. B. Form 9 a.

Cotton Selection No. ____________

PARENT VARIETY ____, U. S. P. B. No. ____________

Inbred ______________________. Year ________. Experimenter ______________________.

Field Notes (*See Notes* ________, *page* ________):

General Notes:

Date Planted	First Bolls Opened — Earliness	Height — Form of Plant	Disease Resistance		Weight Ten Bolls Seed Cotton	Number of Bolls	BOLLS		SEED			LINT						Yield of Seed Cotton	Per cent of Lint	Total Score
							Size	Opening	Smooth or Tufted	Size by Weight	Covering	Length	Color	Fineness	Uniformity	Strength	Drag			

Progeny Notes (*See Notes* ________, *page* ________):

Locality Where Grown	Date Planted	Number Plants Grown	Number Plants Harvested.	Earliness	Height — Form of Plant	Disease Resistance	Size of Bolls	Opening of Bolls	SEED			LINT						Yield of Seed Cotton	Per cent of Lint	Total Score
									Size	Per cent Smooth	Per cent Tufted	Length	Color	Fineness	Uniformity	Strength	Drag			

Individual cotton selection sheet. White. 9¼ × 7 in. (P. B. Form 9a.)

Cotton Score Card.

Cotton Series No.____________

FEMALE PARENT ____, U. S. P. B. No.____________

MALE PARENT ____, U. S. P. B. No.____________

P. B. Form 15.

Object of Hybridization or Selection:

Score on 100 Points:

Earliness ------ points.	Very Early	------
	Early	------
	Medium	------
	Late	------
	Very Late	------
Form of Plant ------ points.	------------	------
	------------	------
	------------	------
	------------	------
Disease Resistance ------ points.	Very Resistant	------
	Resistant	------
	Medium	------
	Poor	------
Drought Resistance ------ points.	Very Resistant	------
	Resistant	------
	Medium	------
	Poor	------
Storm Resistance ------ points.	Very Resistant	------
	Resistant	------
	Medium	------
	Poor	------
Size of Bolls ------ points.	Very Large	------
	Large	------
	Medium	------
	Small	------
	Very Small	------

Opening of Bolls --- points.	Very Good	------
	Good	------
	Medium	------
	Poor	------
Covering of Seed --- points.	Excellent	------
	Good	------
	Fair	------
	Poor	------
Length of Lint --- points.	$\frac{7}{8}$ inch	------
	1 "	------
	$1\frac{1}{16}$ inches	------
	$1\frac{1}{8}$ "	------
	$1\frac{3}{16}$ "	------
	$1\frac{1}{4}$ "	------
	$1\frac{5}{16}$ "	------
	$1\frac{3}{8}$ "	------
	$1\frac{7}{16}$ "	------
	$1\frac{1}{2}$ "	------
	$1\frac{5}{8}$ "	------
	$1\frac{3}{4}$ "	------
	$1\frac{7}{8}$ "	------
	2 "	------
	$2\frac{1}{8}$ "	------
	$2\frac{1}{4}$ "	------
	$2\frac{3}{8}$ "	------
	$2\frac{1}{2}$ "	------

Color of Lint --- points.	------------	------
	------------	------
	------------	------
	------------	------
Fineness --- points.	Very Fine	------
	Fine	------
	Medium	------
	Coarse	------
Uniformity --- points.	Excellent	------
	Good	------
	Fair	------
	Poor	------
Strength --- points.	Very Strong	------
	Strong	------
	Medium	------
	Weak	------
Drag --- points.	Very Strong	------
	Strong	------
	Medium	------
	Medium Weak	------
	Weak	------
Yield --- points.	Excellent	------
	Good	------
	Medium	------
	Light Medium	------
	Light	------

Per cent of Lint --- points.	39 + per cent	------
	37–38 per cent	------
	35–36 per cent	------
	33–34 per cent	------
	31–32 per cent	------
	29–30 per cent	------
	27–28 per cent	------
	25–26 per cent	------
	23–24 per cent	------
	21–22 per cent	------
	19–20 per cent	------
--- points.	------------	------
	------------	------
	------------	------
	------------	------
--- points.	------------	------
	------------	------
	------------	------
	------------	------

Cotton score card. Yellow. 9¼ × 7 in. (P. B. Form 15.)

LECTURE VI.

POLLINATION; OR HOW TO CROSS PLANTS.

1. The Structure of the Flower.

Pollination is the act of conveying pollen from the anther to the stigma. It is the manual part of the crossing of plants. The word fertilization is often used in a like sense, although erroneously; for it is the office of the pollen, not of the operator, to fertilize or fecundate that part of the flower which is to develop into a seed.

The chief requirement in pollinating flowers is to know the parts of the flower itself. The conspicuous or showy part of the flower is the *envelope*, which is endlessly modified in size, form, and color.

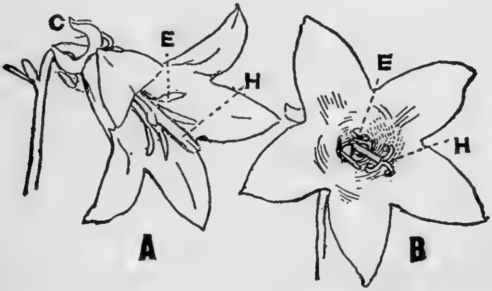


Fig. 1. — Bell-flower.

This envelope protects the inner or essential organs, and it also attracts insects, which often perform the labor of pollination. This floral envelope is usually of two series or parts,—an outer and commonly green series known as the *calyx*, and an inner and generally more showy series known as the *corolla*. These two series are well shown in the bell-flower, Fig. 1. The calyx, with its reflexed lobes, is at C, and the large bell-form portion is the corolla. When the calyx is composed of separate parts or leaves, each part is called a *sepal;* in like manner each separate part of the corolla is a *petal.* In the lily, Fig. 2, there is no distinction between calyx and corolla; or, it may be said, the calyx is wanting. These envelopes of the flower are often much disguised. This is particularly true in the orchids, one of which, a lady-slipper, is illustrated in Fig. 3. The sepals are seen at DD. They are apparently only two, but there is reason to believe that the lower sepal

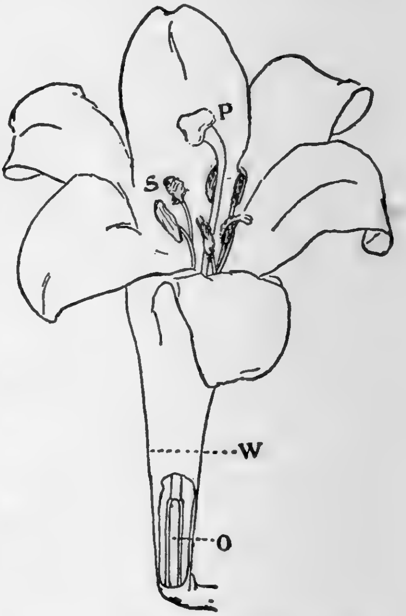


Fig. 2.—Flower of white lily.

is really made up of a union of two. The three inner leaves are the petals, the lower one, H, being enlarged into the sac or slipper.

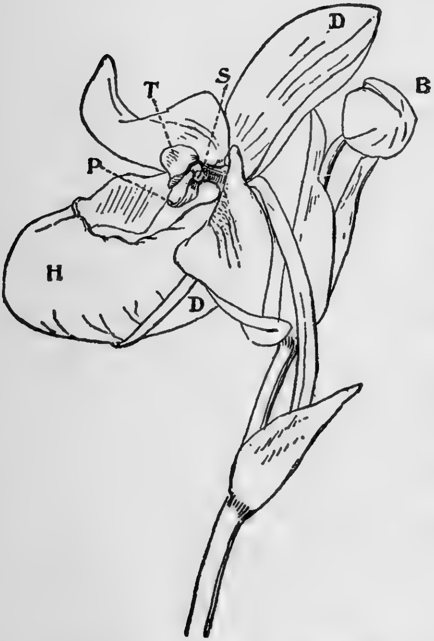


Fig. 3.—Flower of greenhouse cypripedium.

The most important organs of the flower, however, to one who wishes to make crosses, are the so-called sexual organs, the stamens and pistils. They can be readily distinguished in the lily, Fig. 2. The six bodies shown at S are the ends of the *stamens*, or so-called male organs. These stamens generally have a stalk or stem, known as a *filament*, and the enlarged tip as the *anther*. It is in this anther that the pollen is borne. The pollen is generally made up of very minute yellow or brownish grains, although it is sometimes in the form of a more or less glutinous or adhesive mass, as in the milk-weeds and orchids. The irritating dust which falls from the corn tassels at the later cultivatings is the pollen.

The *pistil*, or so-called female organ, is shown at OP, Fig. 2. The enlarged portion at O is the *ovary*, which will develop into the seed-pod. The *stigma*, or the enlarged and roughened part which receives the pollen, is at P. Between these two parts is the slender *style*, a portion which is absent in many flowers.

The stamens and pistils are known as the *essential organs* of the flower, for, whilst the calyx and corolla may be entirely absent, either one or both of these organs is present; and these are the parts which are directly concerned in the reproduction of the species. Like the floral envelopes, these essential organs are often greatly modified, so much so that botanists are sometimes perplexed to distinguish them from each other or from modified forms of the petals or sepals. The particular features of these organs which the plant-breeder must be able to distinguish are the anther and the stigma; for the anther bears the pollen, and the stigma must receive it. In Fig. 1, the stamens are shown at E. In the flower A, which has just expanded, these stamens are rigid and in condition to shed the pollen, but in the flower B, they have shed the pollen and have collapsed. The stigma in this case is divided into three parts, but when the flower first opens, these parts are closed together, H in flower A, so that it is impossible that they receive any pollen from the same flower;

when the stamens have withered, however, as in B, the stigma, H, spreads open and is ready to receive any pollen which may be brought to it by insects or other agencies. In this case, the ovary

FIG. 4.—Flower of night-blooming cereus.

or young seed-pod, which is in the bottom of the flower, is not shown in the engraving.

Some of the particular forms of essential organs are well illustrated in the accompanying photographs. In the night-blooming cereus, Fig. 4, the many-rayed stigma is shown just below the centre of the mouth of the flower, and the numerous stamens are arranged in a circular manner outside of it. The many petals and numerous spreading sepals are also well shown. The hibiscus, Fig. 5, has a central column with the anthers hanging upon it, and a large stigma raised beyond

Fig. 5. — Flower of the shrubby hibiscus (Hibiscus Syriacus).

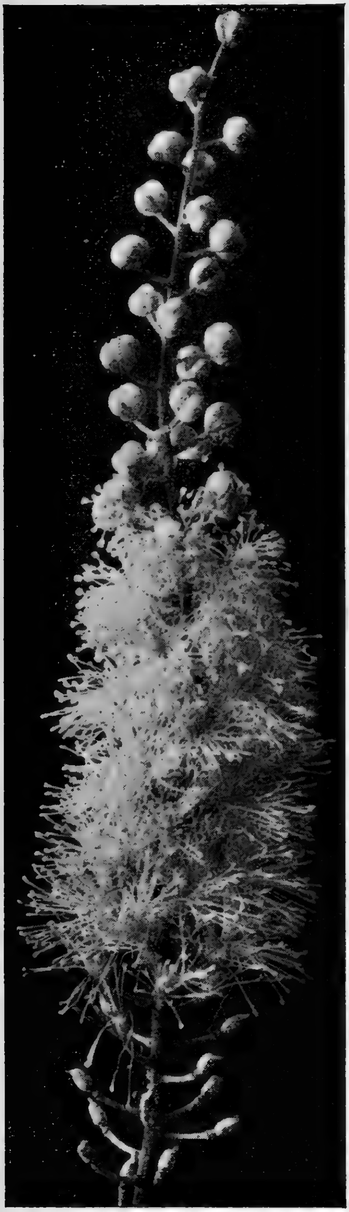


FIG. 6.—Bugbane (Cimicifuga racemosa).

them. The wild bugbane, or cimicifuga, is seen in Fig. 6, natural size. Here is a long spike or cluster of flowers. At the top are the unopened buds, in the centre the expanded flowers with the floral envelopes fallen away,—the fringe-like stamens very prominent,—and below are seen the pistils, the stamens having fallen. These pistils will now ripen into pods, but the tip-like stigma may still be seen on them. The stamens and the long protruding style, tipped with its stigma, are also shown in the fuchsia, Fig. 15. The essential organs of orchids are curiously disguised. They are combined into a single body. In the lady-slipper, Fig. 3, the lip-like stigma is shown at P. Upon either side, at its base, is an anther S. Projecting over the stigma is a greenish ladle-like body, T, which is a transformed and sterile anther. In all lady-slippers, these organs are essentially the same as in the drawing, although they vary much in size and shape; but in most other orchids, the two side anthers, S, are wholly wanting, and the terminal organ, T, is a pollen-bearing anther. In numerous plants, there are many distinct pistils in each flower. Such is the case in the strawberry, where each little yellow "seed" on the ripened berry represents a pistil; and the blackberry and the raspberry, where each little grain or drupelet of the fruit stands for the same organ. A flowering raspberry is illustrated natural size in Fig. 7, for the purpose of showing the ring of many anthers near the centre of the flower, inside of which, in the very centre, is a little head of pistils.

It frequently occurs that the stamens and pistils are borne in different flowers, rather than together in the same flower as they are in the examples which we have studied. In these cases the flower is said to be staminate, or male or sterile, in one case, and pistillate, female or fertile, in the other case. If these two kinds of flowers are borne together upon the same plant, as in pumpkins, melons, cucumbers, chestnuts, oaks, and begonias, the plant is said to be *monœcious;* but if the staminate and pistillate flowers are on entirely different plants, as in willows and poplars, the plant is *diœcious.* The two kinds of squash flowers are shown in Fig. 8. The pistillate flower is on the left, and it is at once distinguished by the ovary or little squash below the colored portion, or corolla of the flower. The lobed stigma is seen in the centre. The staminate flower is on the right. It has a longer stem, no ovary, and the anthers are united into a conspicuous cone in the centre. The flowers expand early in the morning. Insects carry pollen to the pistillate flower, which

FIG. 7. — Blossom of flowering raspberry (Rubus odoratus).

then begins to set its fruit, whilst the staminate flower dies. The flowers of the common wild clematis are shown in Fig. 9. Upon the right are the sterile flowers, which are wholly staminate. On the left, the flowers with larger sepals — the petals are absent — have a cone of pistils in

FIG. 8. — Squash flowers of each sex.

the centre, and a few short and sterile stamens spreading from the base of the cone. These different flowers are borne on different plants in this species of clematis, and the plants are therefore practically diœcious, because the stamens of the pistillate flowers generally bear no pollen. A similar mixed arrangement occurs in some strawberries, except that there are no purely staminate flowers. There are purely pistillate varieties, others, like the Crescent, with a few nearly or quite abortive stamens at the base of the cone of pistils, and others in which the flowers are perfect or hermaphrodite, that is, containing the two sexes.

FIG. 9.—Flowers of clematis (Clematis Virginiana).

The compositous flowers — like the asters, daisies, goldenrods, sunflowers, dahlias, zinnias, chrysanthemums, and their kin — need to be considered in still a different category. In these plants, the head, or so-called flower, is an aggregation of several or many small flowers or florets. Each seed in a sunflower head, for example, represents a distinct flower. Sometimes all of these flowers are perfect, — contain the two sexes, — and sometimes they are pistillate or staminate in different parts of the head; and in some cases the plants are diœcious. In many plants of the composite family, the flowers near the border of the head are unlike those of the centre or disc, in having a long ray-like corolla; and these ray-flowers are frequently of different form from the others in the character of the essential organs. Very frequently the ray-flowers are pistillate, whilst the disc-flowers are generally hermaphrodite. The anthers, in these plants, are united in a ring closely about the style and below the stigma.

The ovary, as we have seen, ripens into the pod, berry, or other fruit; but it is not able to bear seeds until it is assisted by the pollen. The pollen falls upon the roughish or sticky surface of the stigma, and there germinates or sends a minute tube downwards through the style and finally reaches the ovule, which, when fertilized, rapidly ripens into the seed. The nature of this fecundation is not germane to the present subject; but it may be said that only one pollen grain is necessary to the fertilization of a single ovule, but the addition of a superabundance of pollen greatly stimulates the growth of the fleshy or enveloping parts of the fruit. It is important that the person who desires to cross plants should become familar with the stigma when it is "ripe," receptive, or ready to receive the pollen. This condition is generally indicated by the glutinous or sticky or moist condition of the stigma, or in those stigmas which are not glutinous it is told by the appearing of a distinctly roughened or papillose condition. This receptive condition generally occurs about as soon as the flower opens. If pollen is withheld, the stigma will remain receptive much longer than when fertilization has taken place, — in some flowers for two or three days.

The pollen is discharged from the anther in various ways, but it most commonly escapes through a chink or crack in the side of the anther. Sometimes it escapes through pores at one end of the anther; and in other cases there are more elaborate mechanisms to admit of its discharge. In most plants, the anthers and stigma in the same flower mature at different times, so that close-fertilization or in-breeding is avoided. This is well illustrated in the bell-flower, Fig. 1. Here the anthers wither and die before the stigmatic lobes open. In other cases, the stigma matures first, although this is not the usual condition.

II. Manipulating the Flowers.

We are now familiar with the essential principles in the pollination of flowers. Before a person proceeds to operate upon a flower with which he is unfamiliar, he should carefully study its structure, so as to be able to locate the different organs, and to discover when the pollen and the stigma are ready for the work.

The first and last rule in the pollinating of plants is this: *Exercise every precaution to prevent any other pollination than that which you design to give.* The anthers, therefore, must be removed from the flower *before it opens.* This removal of the anthers is known as *emasculation.* Just as soon as this is done, tie up the flower securely in a bag to protect it from foreign pollen which may be brought by wind or insects. As soon as the stigma is ripe, remove the bag and apply the desired pollen, placing the bag on the flower again, where it must remain until the seeds begin to form. The stigma may be receptive the day following emasculation, or, perhaps, not until a week afterwards. Much depends upon the age of the bud when emasculation takes place. It is generally best to delay emasculation as long as possible and not have the flower open; but the operator must be sure that the anthers do not discharge or that insects do not get into the flower before he has emasculated it. The bud at B, in Fig. 3, is nearly ready to emasculate. The older buds on the top of the spike of bugbane, Fig. 6, are ready to operate upon; and so is the bud seen at the left in Fig. 7.

Fig. 10.—Tobacco flowers, showing the parts of the flower, a bud ready to be emasculated, and an emasculated subject.

The manner of emasculating the flower varies with the operator. It is a common practice to clip off the anthers with a pair of small scissors, or to hook them out with a bent pin or a crochet hook. Others use tweezers. For myself, however, I do not like any of these methods, because the anthers are apt to drop into the bottom of the corolla, where it is sometimes difficult to rescue them; and if one uses tweezers, there is always danger that the anthers may be crushed and that some of the pollen may adhere to the instrument and contaminate future crosses. I therefore usually cut the corolla completely off just above the ovary, with a pair of small, long-handled surgeon's scissors (see Fig. 12), removing everything but the pistil. The operation is explained in Fig. 10, which shows the tobacco flower. The flower at the left shows the pin-head stigma in the centre of the throat, and the five anthers surrounding it. The second flower is spread open for the purpose of showing these organs. The third figure is a bud in the right condition for operation. The right-hand figure shows this bud cut around with the points of the scissors, leaving only the pistil. The line at W, in Fig. 2, shows where the flower of the lily might be cut off. The manner of operating upon a compositous flower is shown in the picture of the zinnia, Fig. 11. In this plant the outer florets of the head are pistillate, whilst those of the disc are perfect. It is only necessary, therefore, to remove the central stamen-bearing flowers before any of them open, and to cover the flower up before any of the pistils near the border have protruded themselves. The upper head in Fig. 11 shows the untreated sample, whilst the lower one shows the same with the cone of central

FIG. 11.—Zinnia flowers; the upper head ready for emasculation, the lower one showing the operation performed.

flowers pulled out. This treated head should now be covered, to await the maturing of the stigmas. In many compositous plants, however, the case is not so simple as this, because all the flowers are perfect. In such cases, nearly all the florets should be removed from the head, and a few remaining ones emasculated in essentially the same manner as described for the tobacco, Fig. 10. Whenever flowers are borne in clusters, nearly all of them should be removed and the attention confined to only two or three of them. One is then more certain of getting seeds to set. In some cases, like the apple cluster, only one or two flowers of any cluster ever set fruit, and the operator should then choose the two or three strongest and most promising buds, and cut all the others off.

Flowers which bear no stamens, as the pistillate flowers of squashes, strawberries, and many other plants, of course do not require emasculating. They should be tied up while in bud, however, to prevent the access of any foreign pollen. Indian corn is a case in point. The pistillate flowers are on the ear, each kernel of corn representing a single flower. The silks are the stigmas. If it is desired to cross corn, therefore, the ear should be covered before any silks are protruded, and the pollen should be applied some days later, when the silks are full grown. The staminate or male flowers are in the tassel.

The pollen should be derived from a flower which has also been protected from wind and in-

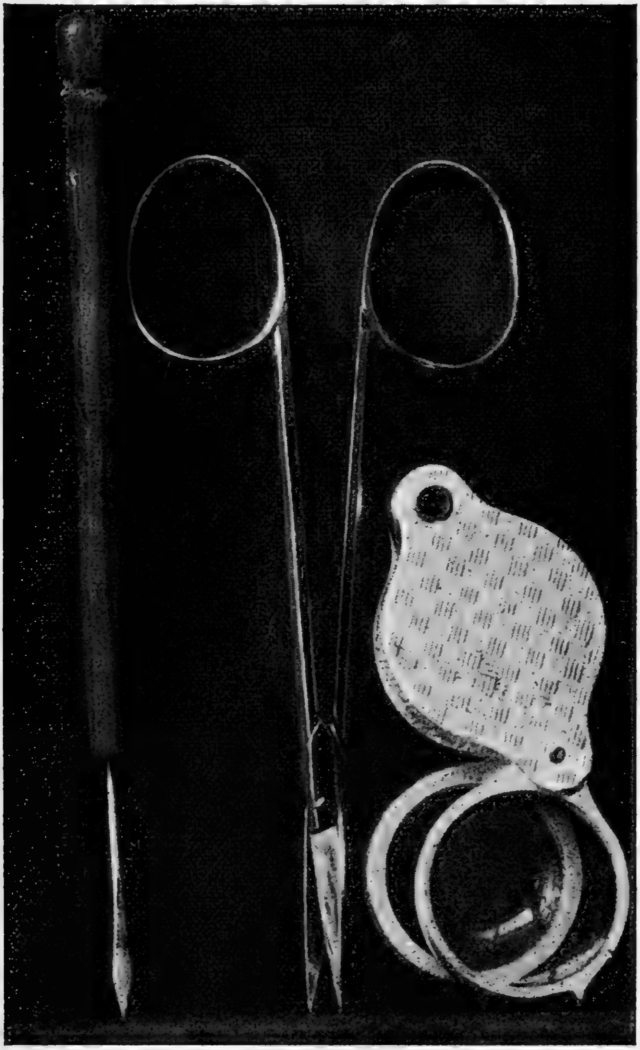


Fig. 12.—Instruments used in pollinating flowers, natural size. Pin scalpel, scissors, lens.

sects, because foreign pollen may have been dropped upon an anther by an insect visitor and it may be unknowingly transferred by the operator. The pollen-bearing parent needs no operation, of course, but the flower should have been tied up in a bag when it was in bud. The pollen is best obtained by picking off a ripe anther and crushing it upon the thumb-nail. Then it is transferred to the stigma by a tiny scalpel made by hammering out the small end of a pin, as shown, full size, at the left in Fig. 12. The stigma should be *entirely covered* with the pollen, if possible. It is often advised to use a camel's hair brush to transfer the pollen, but much of the pollen sticks amongst the hairs of the brush and is ready to contaminate a future cross; and where the pollen is scarce it cannot be conserved to advantage by a brush. In some cases the pollen is discharged so freely that the anther may be rubbed upon the stigma, or even shaken over it, but in most instances it will be necessary to actually place the pollen upon the stigma with some hard instrument. When pollinating house-grown melons and cucumbers, the staminate flower is broken off, the corolla stripped back, and the

FIG. 13. — Ladle for pollinating house tomatoes.

anther-cone inserted into the pistillate flower, where it is allowed to remain until it dries and falls away. In pollinating house tomatoes, an implement shown in Fig. 13, one-third size, is used. This is simply a watch-glass, T, secured to a handle. When the house is dry, at midday, the watch-glass is held under the flowers, which are tapped, and the pollen falls into the glass. The glass is then held up under another flower until the stigma rests in the pollen. It should be said, however, that this pollination of tomatoes is for the purpose of making the fruit set in the absence of insects, not to effect a cross. If the latter purpose were the object sought, the flowers which are to bear the seeds would need to be emasculated.

FIG. 14.—Bag for covering the flowers.

Sometimes it is impossible to secure the pollen at the time the stigma is ready. In some cases of this kind, the intended parents can be grown under glass so as to bring them into bloom at the same time. In other cases, it is necessary to keep the pollen for some time. The length of time that pollen will keep varies with the species and probably also with the strength and vigor of the plant which bears it. As a rule, it will not keep more than a week or two, and, in general, it may be said that the fresher it is the better it may be expected to act. It is best kept in dry and tight

FIG. 15. — Fuchsias, showing the stamens and pistils, and a bud ready to be emasculated.

paper bags, such as are used for covering the flowers.

Something more should be said about the bags which are used for covering the flowers. After having tried every kind which is recommended, I find grocer's manilla bags much the most satisfactory. For most flowers the four-ounce size is the handiest. When the bags are still flat, as they come from the packages, a hole is made through the two overlapping folds near the opening, and a string is passed through it and then tied at one of the folds, as shown in Fig. 14. The bag is then ready for use. Before it is put on the flower, the lower end of it is dipped in water to soften it so that it can be puckered tightly about the stem and thereby prevent the

FIG. 16. — Fuchsia flower emasculated.

entrance of any insect. A bag is put upon the seed-bearing flower when emasculation is performed, and upon the intended pollen parent when the flower is still in bud. The bag may be removed from the emasculated flower from time to time to examine the stigma, and again when the pollen is applied; but it should not be taken off permanently until the pod or fruit begins to grow.

FIG. 17.—Fuchsia flower tied up after emasculation.

By way of recapitulation, let us consider the crossing of a fuchsia flower. In Fig. 15 two flowers are shown in full bloom, with the long style and the eight shorter stamens. The single bud is just the right age to emasculate. We therefore cut off the two flowers and emasculate the bud, as in Fig. 16. The pollen of another flower is applied and the bag is tied on, as seen in Fig. 17. The best label is a small merchandise tag, and this records the staminate parent and the date.

It will be seen that in the operation of emasculating the fuchsia flower we cut off the sepals as well as the petals. In some plants the calyx adheres to the full-grown fruit, as on the apple, pear, quince, gooseberry, or persists at the base of the fruit, as in the tomato, pea, raspberry. In these fruits, therefore, the cutting away of the calyx leaves an indelible mark which at once distinguishes the fruits which have been crossed,

Fig. 18. — Tomato and quince, showing how the sepals were cut off in emasculating.

even if the labels are lost. In Fig. 18 a tomato and quince are shown which are thus marked.

All the foregoing remarks do not apply to the crossing of ferns, lycopods, and the like, because these plants have no flowers; yet cross-fertilization may take place in them. When the spores of these flowerless plants are sown, a thin green tissue, or prothallus, appears and spreads over the ground. In this tissue the separate sex-organs appear, and after fecundation takes place, the fern, as we commonly understand it, springs forth. Thereafter, this fern lives an asexual life and

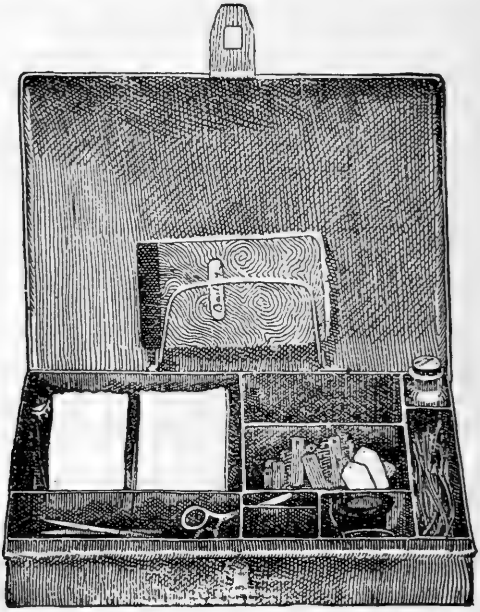


Fig. 19. — Pollinating kit.

produces spores year after year; but it is only in this primitive prothallic stage that fertilization takes place, once in the lifetime of the plant. If these plants are to be crossed, the only procedure open to the gardener is to sow the spores of the intended parents together in the hope that a natural mixing may take place. There are various well-authenticated fern hybrids.

The pollination of flowers is such a simple work that few implements are required for its easy performance. Great care is more important than any number of tools. Every one who expects to cross plants should provide himself with the three instruments shown in Fig. 12, — a pin scalpel, sharp-pointed scissors, and a large hand-lens. If one contemplates much experimenting in this direction, however, it is economy of time to have some sort of a box in which there are compartments for the various necessities. These various compartments suggest at once whatever accessories are wanting, and they hold a sufficient supply

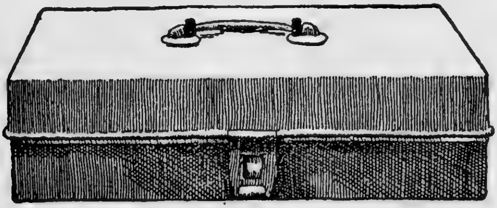


FIG. 20. — Pollinating kit.

for several hundred operations. There should be a compartment for bags, string, lens, scissors, and pencils, tags, note-book, and the like. Figs. 19 and 20 show a convenient case for an experimenter, and one which I have used with satisfaction for several years. This kit is twelve inches long, nine inches wide, and three inches deep.

* * *

Since the above advice was written, much has been said on the subject of methods of pollination. Some of the literature is mentioned in the bibliography at the end of the book. The reader should consult Charles P. Hartley, "Injurious Effects of Premature Pollination," Bulletin 22, Bureau of Plant Industry, United States Department of Agriculture, 1902.

GLOSSARY.

1. The Flower.

Anther. — That part of the stamen which bears the pollen. It is the uppermost extremity of the stamen.

Calyx. — The outer series of floral envelopes, usually green. The various separate parts of the calyx are sepals.

Corolla. — The inner series of floral envelopes, usually colored and forming the showy part of the flower. If it is divided into separate parts, these are called petals.

Essential organs. — The stamens and pistils.

Female. — Said of flowers which have only pistils or the seed-bearing part, or of plants which bear only such flowers; applied also to the pistils in any flower.

Filament. — The stalk or stem of a stamen, bearing the anther.

Floral envelopes. — The calyx and corolla.

Male. — Said of flowers which bear only stamens, or of plants which have only staminate flowers; also applied to the stamens or pollen-bearing organs of flowers.

Ovary. — The lowest part of the pistil, containing the ovules. It is the most thickened portion of the pistil, and it may stand either below or above the petals. The ovary ripens into the fruit.

Ovule. — A body in the ovary which ripens into a seed.

Pet′-al. — The separate parts or leaves of the corolla.

Pistil. — The seed-bearing organ of the flower. It always comprises two parts, the ovary — which becomes the pod or fruit — and the stigma. Usually there is a style connecting the two. Often called the fertile or female organ.

Pistillate. — Said of a plant or flower that has only pistils or seed-bearing organs.

Pollen. — The contents of the anther, capable of fertilizing the forming ovules. It is usually composed of minute yellow or brown grains or spores.

Se′-pal. — The separate portions or leaves of the calyx.

Spore. — A reproductive body, sometimes asexual, by means of which "flowerless plants" propagate; also pollen-grains and embryo-sacs.

Stamen. — The pollen-bearing organ of the flower. Often called the male or sterile organ. Its essential part is the anther. The stalk, when present, is called the filament.

Staminate. — Said of a plant or flower that bears only stamens or pollen-bearing organs.

Stigma. — The top end of the pistil, where the pollen lodges and germinates. It is usually a somewhat expanded surface, and is roughened, or sticky, or moist when ready to receive the pollen.

Style. — The more or less slender portion of the pistil which lies between the stigma and ovary. The pollen-tubes pass through it in reaching the ovary.

2. CROSSING.

Bigener; bigeneric-hybrid. — A hybrid between species of different genera.

Bigeneric half-breed. — The product of a cross between varieties of species of different genera.

Close-fertilization; self-fertilization. — The action of pollen upon the pistil of the same flower.

Close-pollination; self-pollination. — The transfer of pollen to a pistil of the same flower.

Cross. — The offspring of any two flowers which have been cross-fertilized.

Cross-breed; half-breed; mongrel. — A cross between varieties of the same species.

Cross-fertilization. — The action of pollen upon the pistil of another flower of the same species.

Crossing. — The operation or practice of cross-pollinating.

Cross-pollination. — The conveyance of pollen to the stigma of another flower.

Derivative- or derivation-hybrid; secondary-hybrid. — A hybrid between hybrids, or between a hybrid and one of its parents.

Fertilization; fecundation; impregnation. — The action of the pollen upon the forming ovules.

Half-hybrid. — The product of a cross between a species and a variety of another species.

Hybrid. — The offspring of crossed plants of different species. (See page 284.)

Hybridism; hybridity. — The state, quality, or condition of being a hybrid.

Hybridization. — The state or condition of being hybridized, or the process or act of hybridizing.

Hybridizing. — The operation or practice of crossing between species.

Individual cross. — The offspring of two crossed flowers on the same plant.

Individual fertilization. — Fertilization between flowers upon the same plant.

Mongrel. — A cross.

Mule. — A sterile (seedless) hybrid.

Pollination. — The conveyance of pollen from the anther to the stigma (page 252).

The term *cross* is used to denote the offspring of any sexual union between plants, whether of different species or varieties, or even different flowers upon the same plant. It is a general term. And the word is also sometimes used to denote the operation of performing or bringing about the sexual union. There are different kinds of crosses. One of these is the *hybrid.* A hybrid is a cross between two species, as a plum and a peach, or a raspberry and a blackberry. There has lately been some objection urged against this term, because it is often impossible to define the limitations of species, — to tell where one species ends and another begins. And it is a fact that this difficulty exists, for plants which some botanists regard as mere varieties others regard as distinct species. But the term *hybrid* is no more inaccurate than the term *species*, upon which it rests; and, so long as men talk about species, so long have we an equal right to talk about hybrids. Here, as everywhere, terms are mere conveniences, and they seldom express the whole truth.

The word hybrid is used in the above sense in this book, with the exception of the new matter now contained in Lecture IV., in which the newer conception is explained. For an explanation of this change in definition, see pages 153, 154.

3. CLASSIFICATION.

Break. — A radical departure from the type. Ordinarily used in the sense of *sport*, but in its larger meaning it refers to the permanent appearance of apparently new or very pronounced characters in a species.

Bud-variation. — Variation or departure from a type through the agency of buds (pages 28, 191).

Bud-variety. — A variety resulting from bud-variation. Bud-sport.

Family (*Order* in botany.) — A group of genera and species; as *Cupuliferæ*, the Oak Family, *Rosaceæ*, the Rose Family.

Form. — A minor variety, usually transient, produced by some local environment.

Genus (plural, *genera*). — A group or kind comprising a greater or less number of closely related species; as *Acer*, the maples, *Fragaria*, the strawberries.

Mutation. — A term proposed by De Vries to designate the "leaps" or "jumps" whereby species are thought to originate. More definite and specific than "sport." (See Lecture IV.)

Race. — A fixed cultural variety; that is, a cultural variety which reproduces itself more or less uniformly from seeds.

Seedling. — A plant growing directly from seed, without the intervention of grafts, layers, or cuttings.

Seed-variation. — Variation or departure from a type through the agency of seeds.

Seed-variety. — A variety resulting from seed-variation.

Species (plural also *species*). — A term used to designate a group of individuals of sufficient distinctness and definiteness to be used as a unit in classification. It is an indefinite term, differently used by different authors. The species-group does not necessarily represent an entity in nature.

Sport. — A variety or variation which appears suddenly and unaccountably, either from seeds or buds; sometimes, but unnecessarily, restricted to varieties originating from buds, as in this book.

Stock. — The parentage of a particular strain or variety.

Strain. — A sub-variety, or individuals of a variety, which has been improved and bred under known conditions.

Variation. — 1. The act or condition of varying or becoming modified. 2. A transient variety, more or less incapable of being fixed or rendered permanent.

Variety. — A form or series of forms of a species marked by characters of less permanence or less importance than are the species themselves.

Wilding. — A wild individual from a cultivated species.

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FOLLOWING is a list of miscellaneous references to writings on subjects related to plant-breeding. It is not intended to be either complete or comprehensive; but it is sufficient to give the beginning student a fair conception of the range and extent of the literature, and it will enable him to select writings on specific questions that he may be studying. It has purposely been confined largely to horticultural writings.

The literature of cross-fertilization (or cross-pollination) itself — the means by which flowers are pollinated — has been omitted. Those who desire a bibliography of this subject should consult d'Arcy Thompson's list in Mueller's "Fertilization of Flowers."

In the present list I have included many references to the subject of the immediate influence of pollen, although making no special effort to collect such entries.

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