The President's Address

THE PROBLEMS OF PLANT-BREEDING.

By John M. Coulter.

A conspicuous function of such an organization as the State Academy should be the diffusion of knowledge in reference to the subjects called sciences. It is a notable fact that there are as yet no adequate means for this purpose. The public is left to the newspapers and the magazines, and through these channels it is anything but scientific knowledge that is diffused. It is not my purpose to suggest a remedy. We are all too much engaged with our own immediate interests to give this problem the attention it would demand. I have mentioned it simply as an excuse for my subject.

Perhaps no part of the field I represent has had more misinformation diffused concerning it than plant-breeding, for it deals very directly with important human interests, and the public has been like an unwary fish in the presence of some flashy artificial bait. Very probably I would not present this topic to a group of botanists, for they are familiar with it; but my mission here is to represent the botanists before other groups of scientific men, and before the public so far as it will give us a hearing.

The science of botany has had a remarkable history. Beginning with the investigation of plants for what were called their medicinal virtues, it developed with various progressions and retrogressions, until the botanist came to be regarded as about the most useless intelligent member of society. His chief concern seemed to remove him so far from the general human interest, that he was regarded as a harmless crank, at best a man only of ephemeral interest. No such opinion could have developed unless ther[illegible] been some basis for it. It is entirely foreign to my pur[illegible]ver this basis; the situation is simply to be recog[illegible]ct.

The most un[illegible] result of this public estimation of botany was that it [illegible]gered much longer than it was deserved; and consequently, when the other so-called sciences had won public esteem either through their services or their appeal to the wonder-instinct, Botany lagged behind in public recognition, and in most educational institutions was the latest born into the family of the sciences. But finally it also began to render signal service and to appeal to the wonder-instinct.

Without attempting to disparage the wonderful recent development of several phases of botanical activity, phases that have become so developed as to endanger the federal interests of botany as a unified science, there is certainly no one that is attracting more attention at this time, both in its scientific and in its practical aspects, than plant-breeding.

It is not my purpose to recite the notable achievements that are to be grouped under this title, for most of them have been widely published, and are the common property of the scientifically intelligent. Nor is it my intention to make any contribution to the rapidly accumulating store of knowledge in reference to this aspect of plants, for I am simply an intensely interested spectator, sitting on the bleachers but not getting into the game. It is the editor's point of view rather than the investigator's that I can bring to bear upon the subject. Just because so much has been done recently, and because so much of it has been exploited with wide variation in accuracy, I have thought it might be useful to analyze the situation briefly, and to develop some facility in distinguishing between the probable and the improbable. In this country of irresponsible and irrepressible newspapers, magazines, and public addresses, one needs to accumulate a workable collection of antidotes.

The practical aspect of plant-breeding, in a certain sense, is as old as the culture of plants. Long experience in the handling of plants slowly developed a kind of knowledge that became formulated in empirical practice. The general purpose was to improve old forms and to develop new ones. The improvements were numerous, and apparently were possible in any direction determined by the need or taste of man. It was learned that improvements must be kept improved; in other words, that they would not remain constant if left freely to natu... ...us was a laborious, but profitable method of plant-... ...e method known in general as mass culture. The mo... ...individuals were selected and guarded through a series ...ations, until the desired character was built up sufficiently ...ommercial purposes. This is the oldest and still the most widely used method of practical plant-breeding, begun by unconscious selection and merging into intelligent selection. Its limitations are the time and continuous care involved, the lack of constancy in inexperienced hands, and the failure to produce new and constant forms.

In these days of the rapid evolution of the technique of plant-breeding, there is danger of regarding the old method as outgrown and therefore to be discarded. So far as we can see, it will never be outgrown; for general improvement will always be profitable. The newer methods are concerned chiefly with extending the range of our power to secure new forms for improvement.

During all this period of plant improvement by mass culture and continuous selection, the so-called science of Botany was cultivating a singularly distant field. In short, Botany was not practical, and plant-breeding was not scientific. Therefore, botanists on the one hand, and agriculturists, horticulturists, floriculturists, etc., on the other hand, were as distinct from one another as if they had nothing in common. It so happened that the botanists were dealing with very superficial problems in a scientific way, and that the plant-breeders were dealing with the most fundamental problems in an empirical way.

As in any other practice, plant-breeding developed now and then a very successful practitioner, who made distinct contributions in the form of important results; but this represented no more of an advance than does the fact that one cook can surpass another cook in the art of making bread. This caution is necessary, for the results obtained empirically by skillful plant-breeders are too often ascribed to unusual scientific insight. The result is important enough without reading into it what it does not contain.

What may be called the second period of plant-breeding was ushered in when organic evolution began to be put upon an experimental basis. Plant-breeding had been practical, but with no scientific basis; now a new plant-breeding was established, which was scientific, and with no practical motive. The new motive was the accumulation of data bearing upon the problems of inheritance and the origin of species, probably to be regarded as the most important and most difficult of the biological problems. From the formulation of Mendel's law, to its resurrection in connection with DeVries' mutation theory, a decade ago, and on to the present day, the work of scientific plant-breeding has increased in intensity. It would be bewildering even to outline the results, and to do so would not aid the purpose of this address in any material way.

The general result is what might have been expected. We have been plunged into such a maze of facts bearing upon inheritance and the origin of new forms, that the non-partisan is at a loss what to believe. Many of the investigators are so competent that we cannot doubt their data; it is only when they begin to interpret them that we grow cautious. In such a situation, the judicial equipoise can be maintained by several considerations. Such vast and difficult problems as inheritance and the origin of new forms can be solved only by an amount of experimental work that makes the work accomplished seem almost as nothing. It is natural, therefore, that the few points of attack should reveal confusing results. It is also natural for each investigator to extend his own interpretation far beyond the facts upon which it is based. All the facts cited may be true, and all the inferences, when restricted to their facts, may be true also; but the time is yet far distant when we can weave them all together, and many more besides, into a common web, and get some adequate impression of the scheme as a whole. And still, the game is worth all the effort, and those of us who are merely spectators must cheer on the combatants, even to the point of seeming to be partisans.

Out of the maze of data and interpretations, however, certain conceptions are assuming a more definite form. The most significant of these may be stated briefly. The advocates of Mendelism seem to have explained away the majority of cases, among plants at least, that appeared to be contradictory, and in so doing have brought out with much more definiteness that elusive conception called the "unit-character." It is much more evident now than it was a few years ago that the phrase "unit-character" really stands for something that can be manipulated. It is a situation that needs much fuller analysis than it has received, especially from the standpoint of physiological chemistry; and in all probability it must be defined presently in terms of chemistry rather than in terms of external morphology.

Another significant and clarified conception is that of Johannsen's genotypes. In brief, it is directly opposed to the idea of gradual change through selection, each genotype being permanent and unchangeable. Any selection, therefore, in connection with a single genotype, is ineffective; and when selection has been effective, it means that work was begun with a mixture of genotypes. The practical application of this conception is obvious, and will be referred to later.

What seems to be another very significant result of the scientific work of the last few years, is that obtained by Shull in his work on corn, showing that physiological vigor and yield are dependent upon the degree of hybridity. This is related directly to the genotype situation, and is of very large practical importance.

The third phase of plant-breeding can hardly be called a third period, for it is practically synchronous with the second. As a by-product of the work on inheritance and evolution, some of the scientific results have been applied to practical plant-breeding; and the result has been an expansion of its possibilties that may well be called marvelous. In short, practical plant-breeding is now on a scientific basis; and botany has at last attacked the fundamental problems and may be of some practical service, for it includes plant-breeding.

Perhaps it may not be out of place to remind you of the large importance of this combination, for it underlies the welfare of human society. It is a combination of scientific research and its practical application in maintaining an ever-increasing food supply over ever-extending areas. If it is the function of medical research and its aplication to provide for the welfare of a certain per cent of the population, it is one of the functions of botanical research and its application to provide for the welfare of the whole population. Nor is scientific plant-breeding, in its restricted definition, the sole contributor to this end, but bound up with it are physiology, ecology, soil investigations, pathology, and the whole round of interests that touch living plants. In short, there is now possible, for the first time, such a co-ordination of scientific results towards a definite end as to make rapid progress possible.

It may be of service to indicate, by a few illustrations, some of the results of the combination of science and practical plant breeding. One of the first applications to be developed was the production of hybrids. This term is used without reference to the degree of relationship between the crossed individuals. They may be merely different strains or they may be different species; in any event, the result is a hybrid progeny. The original purpose of hybridizing was simply to multiply new forms and thus to increase the range of selection. It was largely chance work, and plants were crossed indiscriminately. So far as practical plant-breeding was concerned, it simply increased the chances for desirable results. So far as scientific plant-breeding was concerned, it accumulated a large mass of facts in reference to the possible range of crossing, the relative facility with which various plants can be crossed, the general features of hybrids, etc.

With increasing practical experience, and with a certain amount of co-ordination of the scientific results, hybridizing gradually became more definite and approximately precise. It was in developing this technique that plant-breeding was said to have passed from chance to certainty. This claim sometimes took the more picturesque form of statement, especially in connection with floriculture, that one could order any kind of plant and the order could be filled within a year. The technique of ordinary hybridizing probably has been exemplified most fully in the operations of Burbank.

The definiteness of highly developed hybridizing consists in the purposeful combination of desirable characters. For example, the size of the Lawton blackberry was combined with the whitish color of a small native blackberry. The purpose and the process were entirely definite, and the result was assured. That the uninformed may not be led astray, it should be said that the resultant hybrids exhibit every combination of parental characters, and it is only when these hybrids are produced by the thousands that there will be any assurance that some one of them will possess the desired combination. In this case, chance is reduced to certainty simply by multiplying the chances. A breeder handling a few hundred plants may get his result, or he may not; but one handling thousands of plants may be sure of it. This multiplication of chances to such an extent that the result is certain is probably the principal reason for such success as Burbank has had. It is needless to say that any control of combinations has not come within the range even of scientific imagination.

It ought to be understood, however, that in most cases hybridization is a process that may put what may be called the finishing touches upon forms already well-developed. It does not produce new forms, but combines old ones. The combination may be very desirable, but the range is restricted, because the process is always working over the old material.

There is a still more fundamental limitation to the usefulness of hybridization as a permanently useful process. Mendel's law has shown that the progeny of hybrids split up in certain simple and definite ratios. In many cases, one half of these plants of the second generation are pure parent forms, and only one half retain the hybrid combination, and so on for each succeeding generation. This means that approximately only one half of the progeny of hybrids come true, a percentage of loss that does not commend the process as one of permanent value. However, there are two facts that save the situation and may save the process as a useful adjunct to more important ones. A few hybrids have been developed that do not seem to split; this is notably true of Burbank's famous triple hybrid, the Shasta daisy. If it is true that some hybrids are not Mendelian, such can be made permanently useful.

The other saving fact is much more important. Very many cultivated plants are not propagated by seeds, and therefore their hybrids are not subject to the Mendelian splitting. Propagation by bulbs, tubers, slips, grafting, etc., includes such a wide range of plants that the sphere of useful hybridization is extensive enough. It will be noted that most of Burbank's combinations are plants that fall within this category. It touches flowers and fruits, chiefly; that is floriculture and horticulture; but not the far more important field of agriculture, where lie the fundamental problems of practical plant-breeding.

Within the last three or four years, a remarkable field of hybridization has been opened by the researches of Winkler and Baur. Ordinary hybridization is effected by the sexual method, which means actual fusion of parental cells, and the development of the hybrid from a single fusion cell. All of the behavior of hybrids noted above is based upon this method.

The new field introduces the production of hybrids by grafting. The influence of the stock on the scion is as old a question as is the process of grafting, but the recent researches referred to have uncovered the situation. If a hybrid is to be defined as the result of the fusion of cells from dissimilar parents, then it remains to be proved whether graft hybrids are true hybrids. But if it is to be defined as a form exhibiting a combination of the characters of dissimilar parents, then grafting often results in hybrids. Those who object to this use of the word hybrid call these combination forms chimeras.

The subject is too new, and the facts are as yet too perplexing, to give to the situation its biological meaning or its possible practical application. One striking feature, however, may be mentioned as an illustration. In some of these graft hybrids, or chimeras, the tissues of the two parent forms remain entirely distinct, and are related to each other concentrically. For example, all of the interior of the body of a chimera may be distinctly that of one parent, and all of the peripheral structures that of the other parent. In other words, such a chimera consists of one parent ensheathed by the other. The superficial aspect, therefore, is that of the parent form furnishing the mantle; and since the sexual cells are derived from the cells of the mantle, sexual propagation from such a hybrid results in progeny consisting of pure forms, through and through, of the peripheral parent. This carries the recognition of hybrids out of the reach of superficial appearance or even of seedling production. Such a combination would stand the test of constancy applied as final in determining a pure race. It can hardly be doubted that we have been introduced not only to a fertile field for the investigation of problems of heredity, but also to great practical possibilities in the manipulation of plants.

A more recent application of scientific results to practical plant-breeding, and one that has extended its possibilities enormously, is the replacement of mass culture, with its continuous selection, by pedigree culture. This method is directly related to DeVries' mutation theory, and has been developed most notably by Nilsson of Sweden. Not only is it really scientific plant breeding, but it includes our fundamental agricultural crops. Nilsson found that his oat and barley crops, grown from pure seed in the market sense, which means seed developed by the old method of mass culture, were very complex mixtures. That is, there was such an amount of variation among the individuals that they seemed to represent many distinct races. Among these individuals, he found represented all the characters he had been trying to build up by the old method of continuous selection, and many more besides. Accordingly the desirable individuals were selected and pedigree culture was established. The selection of a single individual resulted in a progeny that usually came true. The laborious method of continuous selection and building up inconstant forms seems no longer necessary, for the desirable forms already exist, and are constant; and they do not need to be built up, but only discovered and propagated. There is no doubt as to the enormous success of Nilsson with the oats and barley of Sweden; but it is too early to predict the applicability of this beautifully simple method to all other crops.

No citizen of the United States, and especially of Illinois, could fail to raise the question of corn-breeding, perhaps the most difficult of all plant-breeding operations. Does pedigree culture apply here, and if so, has it achieved any important results? The answers to these questions are well-known to plant breeders, but perhaps it may not be inappropriate, in a meeting of the Illinois Academy, to call attention to the extremely important work that has been done in this state in connection with our greatest crop. It was one of our own colleagues, Professor Hopkins, who nearly fifteen years ago proved the individuality of ears of corn, both in physical features and in chemical composition. That is, all the kernels of an ear have the same characteristics provided, of course, cross-pollination has been excluded, and these characteristics are constant. This is certainly individual selection in the strictest sense. Moreover, the range of selection is remarkably wide, for corn is an exceedingly variable plant, probably much more so than are the other cereals. This breeding of corn on the principle of single ear selection, through the wise organization of interest by Hopkins, has resulted in a great increase in the total yield of the state. It ought to be recognized, however, that while selection is made easier than in other cereals, on account of the great number of kernels upon a single ear, it is more difficult to obtain the desired result because of the open and prolonged pollination. With freely exposed "silk," widely carried pollen, and a pollinating period of four or five days for a single ear, it is to be expected that some of the kernels will be hybrids, and these hybrids usually cannot be recognized unless contrasting colors are involved. This means more or less continuous selection in subsequent generations to eliminate the hybrids. It is an interesting obstacle to work against, to know definitely the pedigree on the female side, and to know only vaguely the pedigree on the male side.

Still more recent work in the breeding of corn has developed some new situations. The fact has been emphasized that a field of corn is perhaps the most extensive and complex mixture of elementary forms exhibited by any cereal crop. It is also found that selection down to a single elementary form, followed by rigid pedigree cultures through self-pollination, results in deterioration to a fixed level, which probably represents the normal level of that form. The explanation seems to lie in the fact that hybrids from nearly related parents are more vigorous than either parent; and therefore an isolated form that does not enter into a hybrid deteriorates to a certain point. This work suggests, therefore, that while pedigree culture is essential to isolate elementary forms, to obtain what the bacteriologist would call pure cultures, so that they may be recognized and manipulated with intelligence, the ideal second step would be approved combinations of elementary forms, to obtain the increased vigor of a hybrid. In other words, it is first isolation, which means individual selection and pedigree culture, and second recombination.

This local illustration from our own dominant crop indicates that the method of individual selection, or pedigree culture, is sound in principle, but that its application to any particular crop is a special problem, involving a special technique.

An illustration or two of the possibilities of pedigree culture may be of interest. The problem of resistance is one of the most important in connection with plant-breeding. For example, it is most desirable to secure resistance to such things as disease and drought, and individual selection has suggested a method of attack.

The original method of combatting the destructive diseases of culture plants was to determine the parasitic form inducing the disease, learn its life history, and discover some means of killing it or of preventing its development. The incidental result of this method has been a gain to science in a greatly increased knowledge of the life histories of a most interesting group of organisms. It can hardly be claimed that there has been any gain of equal value to practical plant-breeders. The introduction of individual selection suggested a new method. It was observed that after the most destructive attack of a given disease, certain individuals would remain unattacked; and it was inferred that one of the characters of such individuals was immunity to this disease. Pedigree culture should perpetuate this character and establish an immune race. A certain measure of success has followed the experimental work undertaken to demonstrate the possibilities, but new situations have developed that lead to other complications. For example, it is discovered that an immune race growing on one area may not be immune when grown upon another area; also that an immune race may not always be immune on the same area. This probably means that the tone of the plant is not the same under all conditions, and that as this varies the power of resistance varies. In this way investigations lead back to the physiology of the plant that is to be guarded against attack. As is so often said in these days, we must shift our attention a little from the disease-producing organism to the physiology of the patient, both normal and pathological.

The original method of combatting drought was to irrigate in regions of perennial drought, and to take the chances in regions of possible drought. Pedigree culture suggested the possibility of discovering drought-resisting races. A case in point is the recently discovered wild original of the wheat in Palestine. This plant is certainly more resistant to drought than are any of our strains of wheat, which have probably been derived from it through many centuries of culture. It would seem easier to select a race already hardy, than to induce a pampered race to become hardy. Aaronsohn, therefore, in his Palestine experiment station, proposes to propagate this hardy race and distribute it. The interest of our country lies in the fact that such a wheat would not only mean a surer crop in the present wheat areas, with their possible drought, but would also enormously extend the wheat area into regions of well-nigh perennial drought. A vision such as this is most attractive, for it deals with extremely important facts, with values of the highest order to the general welfare of the country. But it must be remembered that we are not cultivating wheat for its hardiness, and the first question to ask is as to the quality of the grain that this hardy plant produces. It certainly must be improved before it can replace the strains we have learned to depend upon, in spite of their sensitiveness to the accident of drought and their restricted range. This means long and patient and scientific cultural experiments, such as are being conducted by Buffum in Dakota, in the attempt to secure a combination of hardiness to drought, which we desire, and quality of grain, which we possess. I see no reason why the vision should not be realized, but you need not invest in arid land for immediate use as wheat fields.

And now within two or three years there has come a race of corn from China that is peculiar in its drought-resisting structure. If we know anything about the wild ancestry of corn, this Chinese race has arisen from American stock; and since the Chinese records show that it was in cultivation at a time preceding the "discovery of America" that we celebrate, it lies outside the field of a botanist to explain the method of its arrival in China. In any event, its peculiarities are very striking, emphasizing the divergent evolutionary results that may be obtained by the geographical isolation of a single strain or of a few elementary forms. The drought-resistant structure developed is of such an order that it would not only insure corn crops against the occasional untimely drought, but also would present the possibility of extending the corn area into drier regions.

But this again is only the vision of a possibility that lures the plant breeder on to investigation. As in the case of the Palestinian wheat, we are not breeding corn for drought resistance alone, and it will take many plant-generations of the highest type of scientific plant-breeding to determine whether we can combine this drought-resistant structure with the high grade quality and yield we have obtained already in our cultures.

In presenting these fleeting glimpses of the problems and the accomplishment of plant-breeding, I have intended to emphasize not only its fundamental importance to both biological science and agricultural practice, but also the inextricable entanglement of the two. Any result of scientific plant-breeding, representing as it must additional knowledge of the processes of evolution and of heredity, may become of practical service; and any result of practical plant-breeding, involving as it does extensive experiments with plants, may prove to be of great scientific importance. They are mutually stimulating, and both are necessary to the most rapid development of knowledge.

It is the proper balance between the two that must be maintained. The physical needs of man, great as they may be, must never obscure the intellectual needs of man, especially as the trained intellect is the speediest agent in meeting physical need. On the other hand, the intellectual needs of man, noble as they may be, must never lose sight of the fact that the speediest results are obtained by the enormous increase of experimental work under the pressure of physical necessity.