The following paper was read by W. M. Hays at the International conference on plant breeding and hybridization in New York, 1902:

BREEDING FOR INTRINSIC QUALITIES.

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The aggregate of wealth annually produced in America by means of domestic plants and animals is valued at several billion dollars. A liberal allowance for fields and flocks in the hands of men who will not seek or even receive blood of improved plants and animals will easily leave annual products worth two billion dollars, which may be brought under the breeder's influence. Burbank and other breeders of plants, and of animals, have abundantly proved it is practicable by breeding alone to increase values ten per cent. Ten per cent of two billion dollars is two hundred million dollars. No doubt, breeding operations, as now developed, will increase this annual product two per cent in twenty years, or forty million dollars annually. It is fair to believe that an additional increase of eight per cent, or one hundred and sixty millions additional annual increase, may be produced by devising and extensively using much better scientific methods of breeding. One per cent of the total increase should be a sufficient annual expenditure to produce the magnificent increase which seems in reach, if the work is properly carried out. The soil is a vast mine, and our plants and animals are parts of our mining machinery. If by spending one per cent of the value of the output on these machines we can increase the output ten per cent, we are "penny wise and pound foolish" not to do so.

This problem is distributed from the gentle violet to King Corn, and from the brilliant goldfish to the queenly cow, and includes many microscopic organizations. On the side of wealth production this problem lies mainly in a score of staple crops, and in the four great species of domestic animals. But in addition there are vast financial interests in species of fruits and flowers and in the minor species of economic animals, including some fishes, oysters; also economic insects, bacteria, etc. The interest does not stop with the financial, but there are ethical and scientific interests of vast import. Improved plants and animals, and the interest which is connected with their breeding and production, make for a better civilization.

Pedigrees, distinguishing marks, performance records and the attractive presence of the living product of the breeder's art have an inspiring interest which is uplifting. People who have highly bred plants and animals farm better, thrive better, enjoy life better and live better. Breeders and growers of improved plants and animals have a delightful source of zest, unfelt by ordinary mortals. Humanity relishes touch with improvement. The hybridizer is a creator of values and his every improved product, besides serving in its own generation, becomes a new foundation

for an added story to the superstructure of economic or artistic production.

Man's influence on plants and animals was Darwin's best clue to the science of heredity. Hereafter scientific breeding promises to be one of our best means for studying the nature of man, as well as of plants and animals. Man, aided by social organization, is making tremendous strides in self-development. The rapid strides found possible in improving species of plants and animals begin to give hope that race development may become feasible. The subject of breeding is apparently approaching a vastness, a profundity and a widespread interest comparable with its possibilities.

As minds flock about a new thought in invention, literature or art, and perfect it, so scientists have long hovered, spellbound, about Darwin's theory of natural evolution. That man can turn this idea to immense account has heretofore received only a moiety of its due. Though the strenuous contest which his theories precipitated caused him to lay the stress on the historical rather than on the future economic phase of his brilliant work, as relates to animals and plants, Darwin saw both facts as few of his followers have appreciated. But there is developing a deeper appreciation of his work in relation to the possible evolution of domesticated species. Biologists, as well as practical breeders, are becoming interested in the possibilities of artificial evolution, carried out scientifically and on a scale commensurate with its necessities and importance.

The most important business principle brought out during recent years by Burbank and others is that by carefully growing and testing very large numbers of plants, improvements may be made which will far more than pay the cost. Galton showed that there is only one remarkable man in several thousands. Animal breeders have come to realize that there is only one remarkably prepotent and effective sire in many; e. g., Messenger, the father of trotters, and Stoke Pogis, sire of a family of superior Jersey cows. Gideon, Patton and other apple breeders find only one superior apple among very many seedlings. Burbank throws away piles of berry vines as large as straw stacks in the effort to find a few superior individual mother plants.

The old time proposition that like begets like, that there are variations in some individuals, with occasional cases of atavism, is neither distinct nor definite as a rule of business action. Breed from the best is a good rule, but its meaning is comparatively unimportant in variety and breed formation, unless changed to read: Breed from the very best from among very large numbers. To utilize large numbers in an effort to secure the one or several best as progenitors of a new race, system must be used in growing, measuring and testing. Statistical methods, instruments of precision, and machinery, also business and public organization, must be devised and utilized extensively, especially with some of the most important wealth producing species.

Selection requires nearly the whole labor and expense, in most cases hybridizing only requiring a fraction of one per cent of the work of the

improver of plants and animals. Plants may be divided roughly as to methods of breeding into three classes, according to their manner of propagation. The apple will serve as an example of the first class, where we reproduce the mother plant asexually, as by buds or cuttings, there being only bud variation and no further adulteration through fertilization. Wheat, which is self-pollenated, but which we reproduce by sexually produced seeds, will serve to illustrate the second method of breeding. Corn, which is accustomed to the freest and widest cross-pollenation, will serve to illustrate the third, and by far the most difficult general method of breeding. I use the term "breeding" in its general or widest sense, so as to include all operations which assist in securing blood lines better adapted to the desired purpose.

The first operation is securing the best foundation stocks, whether utilizing varieties at hand known to be superior, or by accession from the outside, securing others and testing them beside known standard sorts. We should always place much effort on securing the best possible start. Of the possible final improvements more than half is ofttimes secured by a wise choice of foundation stocks. Not infrequently ultimate failure is met because of a hasty and ill advised start. Breeders are in competition, and no one should allow his competitors to start with superior foundation stock and he with a handicap. This selection of original varieties should be from among as large numbers as practicable, and with a broad knowledge of the correlated qualities required to make up the largest unit of economic and artistic values in the desired line. As the methods of selecting are here much the same as selecting among newly formed varieties, details will be passed over.

In making hybrid varieties the mere manipulations of emasculating and cross-pollenating, though sometimes tedious, are usually exceedingly simple, and in many cases may best be left to natural agencies. The choice of varieties to mate, however, presents unusual difficulties. In some cases, e. g., Burbank's plums, experience has proven that the union of certain blood lines often results in an unusual proportion of superior progeny; and in animal breeding certain out-crosses have so often proved superior that they have gained popularity. But for the most part crosses must be made between those varieties which most nearly approach the desired ideal, and which will supplement each other; and then the chances must be taken of securing occasionally superior parent plants and effective blood lines. True, in some cases, we can gradually introduce a small proportion of the attenuated blood of some form strong in a needed characteristic, but undesirable in others. Thus the thirty-second part of the blood of a hardy native crab might be utilized to make a hardier form of apple for the far Northwest. Since hybrids may combine their innumerable characteristics in such a multitude of forms it is not strange that we find it necessary to seek from among tens and hundreds of thousands that one individual or small group of plants which shall possess the desired correlation of qualities. If all the words of a dictionary were on slips of paper and placed indiscriminately in a pile, we could be certain of securing a given word only by looking over the whole pile. The combinations possible in hybrid individuals between two species or varieties are vastly more numerous than the number of words it is possible to make by combining the twenty-six letters of our alphabet; and where the blood of three or more species is intermingled the

complexity is made still greater. We must expect to select from among large numbers.

Varieties Multiplied Asexiially.

In species like the apple the opportunities of improvement by selection within the variety, without seed reproduction, are relatively slight, because confined to bud selection; though even in buds the natural impulses of the mixed blood, aided by environment, cause useful and valuable variations, apparently differing in their values only in degree from variations arising directly from seed reproduction. Seeds which are hybrids between known varieties should generally be used where practicable. Here the selection is carried out by simply growing immense numbers, digging out all unpromising trees, fruiting the promising ones, and by making root or top and bud grafts, thus extensively testing the very few best, and finally propagating only those which prove so superior as to warrant their commercial use. If better methods cannot be devised for securing to originators remuneration for their work, the breeding of this class of crops should be taken in hand extensively at public expense. In Minnesota something is being accomplished by the State Horticultural Society. It has offered a premium of $1,000.00 for a choice apple, with certain prescribed qualities. But that sum can pay for only one variety, and even that liberal premium will not give enough stimulus of apple breeding. The public cannot afford to longer refrain from investing much larger sums in apple breeding.

Varieties Multiplied by Self-Pollenation.

Any reasonable expense may properly be used in the breeding of our great staple crops, where hundreds of millions of dollars hang on the breeding values of a comparatively small number of superior plants. Theory dictates and practical experience has proven that the employment of a large number of plants is an economical necessity in breeding such crops as wheat, oats, barley, etc. The following brief statement of a plan for breeding wheat is essentially that in operation at the Minnesota Experiment Station, but is adapted to the conditions of starting anew in a State experiment station:

A large number of chosen varieties, a hundred or more, are secured from regions with conditions most like that for which the varieties are desired. In a few years these are reduced to the ten, more or less, which are productive of the largest value per acre. The breeding may be begun before all these varieties have been given field trials, if one or more varieties are already at hand which are useful, that they may be made more useful to the State at the earliest moment.

For convenience of statement, after testing three to five years, we will assume to choose five superior varieties for foundation breeding stocks. At every point where selection is practicable the best should be chosen. From field plots of each of the five varieties superior spikes are chosen. These are shelled and 10,000, more or less, superior kernels are selected from each variety. Each of these is planted by itself in a bed with its fellows in such manner that each plant may have the same opportunity as each other plant. Beds four by forty-two feet, with two-

foot alleys between the sides and six-foot alleys between the blocks, at the ends of the plots, are made level and the seed bed made fine and of very even texture. To insure good mechanical conditions and an abundance of moisture in the spring, also freedom from insects, the land for the field crop nursery is summer fallowed the previous year, where practicable to do so. An effective machine has been devised for this planting. It rests on planks lying in the alleys on either side of the bed. One man sits on the machine and drops into each of fourteen cups one or two seeds. He then throws the frame carrying the cups over and the seeds fall down fourteen tubes, each of which extends into the soil to a uniform depth of two to three inches. A second man with a lever throws the machine forward four inches, and as the seeding tubes are four inches apart the hills are in squares, each plant having sixteen square inches of soil room. Before the plants have begun to stool the beds are carefully gone over, and only one plant is left in a hill.

When ripe the poorer plants are cut off with sheep shears, leaving about 500 of those of each variety, or 2,500 in all, which appear to be the heaviest yielders. The bunch of several spikes of each of these plants is put into a separate packet, properly numbered, and taken to the laboratory and weighed in the chaff. One hundred of each variety, 500 plants in all, which weigh heavy, are shelled and inspected as to quality. Two hundred or more of those yielding the highest value per plant are chosen, and the second year loo of the best seeds are planted from each of the 200 mother plants. Two border rows are planted about each plot, and these are removed before harvest. At harvest time ten superior spikes are saved from as many superior plants in each plot, and the seeds from these are saved to plant a similar plot the third year from -each stock or variety from the 200 mother plants, respectively. There are usually a few blank hills, and it is necessary to count the plants as harvested. Shears with automatic counting attachment are here needed to facilitate the work and to make the counting more accurate. The grain is tied into a bundle, the heads of which are wrapped in muslin to prevent loss from sparrows, etc., and the bundles are tied to stakes to dry. The bundles are threshed in especially arranged machinery, which does not lose nor mix the grain. After adding the weights of the bulk grain and that shelled from the ten spikes chosen for seed the total is divided by the number of plants, thus giving the yield in grains per plant of the progeny of the 200 mother plants. By using the seeds from the ten spikes a similar test is made the third year, and in like manner a test is sometimes made the fourth year. The averages between the yields of the average plants for the two or three years give pretty good indexes to the power of the blood of each of the mother plants to produce heavy yielding progeny under conditions nearly like those met by the wheat plants in the fields. In other words, we thus secure a good measure of the "projected efficiency," or breeding power, of each of the 200 mother plants. The seeds of each of the fifty best of the 200 stocks may now be separately planted in field plots, making fifty varieties; or, five, more or less, of the plants very similar in appearance may be mixed together, thus greatly reducing the number of varieties. These are grown the fifth year in increase plots, so as to secure sufficient seeds for plots of one-tenth or one-twentieth of an acre in area. The sixth, seventh and eighth years the fifty varieties are grown beside their parent varieties and other standard kinds in field test plots. Sufficient superior stocks

are handpicked out of each plot to furnish seed for planting the plot the next year, thus keeping the plot pure from mechanical mixture and gaining slightly on the selection toward larger yield. During these three years tests are made not only of yield and of quality, as determined by inspection, but milling tests are also made of the quality of the flour from each variety. At the end of this period averages are made of the trials for the three years, and each wheat is studied as to its relative value producing power per acre. Possibly five out of the fifty are superior to the remainder. These are furnished to experiment stations in surrounding States, which are in a co-operative or- ganization, that they may give the new sorts further trial for the use of the originating station, and also for their own use. If, after one or two years' trials at several stations, or after further trial at the originating station, one of these wheats shows a value per acre greater than any other wheat grown, it is rapidly multiplied. Instead of distributing it free, the pedigree is placed behind this new variety, and it is sold at a price much above the current prices of ordinary seed wheat, but much below its real value. It is sold to seedsmen, seed growers and farmers, and so distributed throughout the State that all who will make a specialty of growing superior seeds for sale may soon have a chance to grow it. This has proven a very effective way of widely distributing a variety. Even sorts bred only for superior yield per acre, with no ordinary varietal distinguishing marks, are thus widely distributed.

Distinguishing marks are very useful, but, often to combine breeding for distinguishing marks with breeding for intrinsic qualities has defeated the whole economic purposes, e. g., breeding clover at the Minnesota Station for the first ten years of effort in that direction helped to lead to temporary failure. We tried to breed hardy clover with flowers of lighter color.

This method of breeding wheat costs money. "The proof of the pudding is in the eating," however, and one variety thus originated and distributed, Minn. No. 163, has already paid the bill for breeding this and other species of field crops by the Minnesota Station. The farmers' reports show that this variety yields a dollar per acre more than the wheats it is supplanting. We estimate that in 1902 there was grown in Minnesota 60,000 acres of this variety; also 20,000 acres in North Dakota. That this has resulted from 200 bushels distributed in 1899, 100 in 1900 and 200 in 1901 seems at first remarkable. This emphasizes the fact that even a variety not differing in appearance from a kind commonly grown in the State may be widely distributed by putting behind it a statistical pedigree and by careful work in breeding and distributing which will gain the confidence of the growers. Open-palienated plants, also animals, must be bred in many ways in a manner radically different than bacteria, or apples, or than wheat or oats, where adulteration by mixing is not continued.

Open-pollenated species and animals are accustomed to more or less cross-breeding, and in many cases a mixture of blood is necessary to their reproductive vigor. Here we have the more complex problem of securing mixtures of blood lines which have a high "projected efficiency' 1 It is harder here to fix types, to attain a settled character of blood lines which are constantly tending to reorganize into new combinations of

characters so as to have a strong and constant efficiency in the production of large values along given desired lines. Besides, we cannot breed a large number of open-pollenated varieties in one nursery, nor on one farm, unless it be a very large one. In corn, for example, the importance of great care in securing a superior foundation stock is even more important than in wheat, because the number which may be kept under trial is limited to so few. After having chosen the variety, the very choicest plants should be chosen from among very large numbers, as from large fields. These should be most carefully tested as to yield of grain and general character of plant, time required to mature, etc. In some cases the composition of the kernels may be determined. One hundred or more superior plants are chosen, and a centgener row planted from each. Twenty or more of the best yielding rows with good plants are chosen, and from among the plants in each of these rows ten or more of the best plants are chosen and tested. The best of these are used for planting thirty to a hundred centgener rows the third season. Care is taken to not reduce the number of original blood lines to below, say, five, or even ten. Soon the selecting should begin to respect certain types, that the variety may be reduced to a .more popular appearance. But retaining the high yielding types is of first importance, and a check should constantly be kept on the work. There is some danger of making the variety uniform, or "thoroughbred," in appearance and mongrel in yield. Breeders of Shorthorn cattle sometimes find that they have "thoroughbred red" families which are "scrub milkers" and not very thoroughbred uniform in beefing qualities. Once the value per acre of the variety of corn has been materially increased, the very choicest ears only being needed for the nursery breeding, seeds from the best remaining ears may be used in field planting, and seed grown from this selected stock for the market. The nursery must be large to give wide opportunity for securing superior individual plants and for testing the breeding power of many mother plants. Every year, or every few years, a commercial stock of seed may be drawn from the nursery, taken to the field and there multiplied. It may pay to grow corn in the nursery only every alternate year, growing in alternate years in large fields, for which purpose the seeds of the various blood lines are indiscriminately mixed. No one can settle this and many other similar questions until experiments are made.

Just now there is an excitement about Mendel's Law. We hope that law will help to clear up many questions, both scientific and practical. But there are thousands of theoretical questions with practical bearing. Some of these may be as important, or even far more important, than Mendel's Law. Let me urge that we extend, broaden out and intensify our endeavors in investigation along these lines. Let us urge the large equipment of laboratories and experimental grounds for plant breeding at public expense. Let us find and introduce those laws of business which will enable the private individual to secure larger rewards for supplying the world with new creations. The scientific workers in plant and animal improvement should realize that the people will appreciate large economic results, and will gladly urge the expenditure of what appears now very large sums of money, if we show as large a dividend as we might. Creating values and scientific work go hand in hand. The production of new wealth will supply the wherewithal to support scientific research in natural and scientific evolution. Scientific research, on the other hand, will furnish the laws to make easy and popular the production of wealth by

dealing with the living forms we depend upon to produce such a large part of the commodities needed by the world.

The most important law is that by hybridizing we can create new values. The next most important law is that by selecting from among very large numbers we can segregate the individual plants or animals carrying these new powers and multiply them for our use. The great business proposition is that values can be enormously increased at relatively slight expense. Are not the government, the States and private individuals ready for larger cooperation, not only to learn more about how to breed, but also to extensively improve our useful friends, the 'plants and animals, upon whose powers of inheritance we so fully depend?

The Chair: I believe there is a great deal in what Professor Hays has told us; that the principle which breeders of animals have found to be necessary, to breed, as they call it, from performance, should be used in our plant work.