exception of Honduras, which seems well adapted to lands contiguous to the Mississippi River, that can be considered well suited to its environment.

As a basis for the improvement of the rices of the Southwest, the office of Grain Investigations, of the United States Department of Agriculture, began in Louisiana in 1905 the testing of more than three hundred varieties of rices, which through various sources had been collected from nineteen countries of the world. This work has led to the selection of twelve varieties which possess desirable qualities for field conditions, and has furnished data, which will be used next year in breeding a hard translucent kernel, that, under present milling methods, will produce a larger percentage of head rice, a need which farmers and millers acknowledge to be worthy of effort.

FIELD METHODS IN WHEAT BREEDING.

M. A. Carleton, *Washington, D. C.*

The chairman of the Committee on Breeding Cereals has asked me to present a résumé of methods in wheat breeding to date. This is a very broad subject and the present condition of wheat breeding operations is somewhat tangled. I have decided therefore, with the consent of the chairman, in order to be at all thorough, to discuss only one phase of the subject—that of field methods.

Probably in no other line of agricultural experiments have we conducted our operations with less guidance from those who have had experience, than in cereal breeding, and yet in no other line of work is it more important to make a proper beginning. With a view of helping those who are now beginning their wheat breeding work I hope to present some definite principles derived from the experience of many workers, that will give a basis for concerted action and uniformity of operations in the future.

Only fifteen years ago no wheat breeding of any consequence had been done in this country leading to the establishment of distinctly additional wheat varieties of proved value, except that of C. G. Pringle and A. M. Jones. Today from twenty to twenty-five public and private experimenters are working on this line. Nearly every man has some one method distinctly his own, and when we consider all operations in detail we find there are nearly as many methods as there are experimenters.

As an official of the U. S. Department of Agriculture, in charge of work in coöperation with other institutions in various States and Terri-

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tories, I have had a good opportunity to note the work of other cereal breeders. I shall present herewith the outlines of field methods in wheat breeding practiced by a number of experimenters, obtained from consultation and correspondence with these men and from observations of the work; also the methods of the Office of Grain Investigations, of the Bureau of Plant Industry. From these experiences it is possible to draw certain conclusions that seem to me to be very valuable for future work.

METHODS AT THE MINNESOTA EXPERIMENT STATION.

The extensive wheat breeding work of the Minnesota Experiment Station, originated by Prof. W. M. Hays, now Assistant Secretary of Agriculture, was begun in 1892. In the experiments at this Station more than at any other institution in this country, the early work was confined almost entirely to the development of methods whereby large numbers of plants could be grown under uniform conditions and examined for individual merit. For some years individual plants were grown in rows—one foot apart in the row—but this plan was rejected in 1898, as the plants did not grow under uniform or field conditions, and it was impossible to grow a large number of plants or to make accurate comparisons. The next plan developed was that of growing groups of one hundred plants (centgeners)—the progeny of a single mother plant—in beds so that the plants were four inches apart each way. At harvest time these groups were inspected and the best ten plants selected from each group. Measurements of yield and grade of grain, stiffness of straw, etc., were then made on each of these selected plants. The group was propagated in the succeeding year from the plant which measured up best in this test. This scheme gave the breeder the chance to eliminate the weak individuals in the group, and thus far was successful. It failed, however, in allowing comparisons between groups which were the progeny of single mother plants, except as such comparisons were made between the selected plants in each group the first year from the foundation bed.

To actually study the productiveness of an average group of plants resulting from a single mother plant, the various groups must be carried to the field plat test. Thus a large breeding nursery demanded extensive field trials—too extensive to be practicable. It was seen that some plan must be developed by means of which the productiveness of the mother plant—as revealed in the progeny—could be tested in the nursery and only the most productive groups carried to the field plat test.

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In 1898 the breeding nursery was put under a plan commonly known as the centgener plan, which may be briefly described as follows:

Foundation beds of superior stock are introduced or foundation beds of hybrids are grown—the plants being four inches apart each way. By elimination the most productive individuals are sorted out and each selected plant becomes the progenitress of a race of wheat. The year following this selection of mother plants a group of one hundred plants (centgener) is planted from the seed of each selected plant. Thus many groups of progeny are grown in comparison with one another under the most uniform conditions that it is possible to provide. At harvest time the best ears (spikes) from the best five plants are saved to extend the test into future years. The grain from the remaining plants is threshed out in bulk. The total weight of grain produced by each centgener is divided by the number of plants harvested, thus giving as a basis for comparison the average yield of grain per plant. After three to five years' centgener trials an average is compiled of the performance records of each centgener. A few of the most productive types are carried to the field for trial in comparison with standard varieties. By this method a statistical record shows the ability of the mother plants to transmit their productiveness into future generations of plants. Those groups which failed to excel in the centgener trials are discarded at this point, and thus much of the expense of field testing is saved.

Along with the development of this plan for studying the performance record of generations of plants there arose the necessity for a machine which would plant the centgeners with a relatively small amount of labor. In the early years of work the planting was done by punching a hole in the soil and dropping the seed in by hand. Only a small nursery could be planted in this manner, and only a few groups of plants, therefore, could be tested. In 1902–1903, Professor Hays and Wm. Boss invented a centgener planting machine, which will plant 180–200 centgeners per day with the labor of two men. This machine makes it feasible to grow hundreds of thousands of plants under uniform conditions, and thus permits the breeder to conduct his search for prepotent individuals among vast numbers of plants.

In the accompanying table a statistical history of spring wheat breeding at the Minnesota Agricultural Experiment Station is exhibited. It shows the growth in the nurseries from 1897 to 1907.

It is not the purpose of this paper to give the results of wheat breeding by different experiment stations, but it may be of interest in this connection to state, for the information of those who do not know, the history

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of the three most important new strains of wheat developed at the Minnesota Experiment Station. These are without question Minnesota Nos. 163, 169 and 188. No. 163 was developed as a simple selection from single mother plants, starting with selected seed of Powers' fife. No. 169 was developed in a similar manner from selected seed of Haynes' blue stem. Both these varieties are therefore simply selections, and No. 163 is properly a fife, and No. 169 a blue stem, facts probably not generally known, though the wheats themselves have been much advertised. Only one of these varieties, No. 188, is a hybrid wheat. It is really an improvement by selection of the variety Preston, produced years ago by Dr. William Saunders, as a cross between fife and Ladoga. This, too, is the only one of the important pedigree varieties developed by this experiment station that is a bearded wheat. An

TEN YEARS' GROWTH IN THE SPRING WHEAT BREEDING NURSERIES OF THE MINNESOTA AGRICULTURAL EXPERIMENT STATION.

YEAR.	NO. OF CENTGENERS; STRAIGHT SELECTION	NO. OF CENTGENERS; HYBRIDS.	NO. OF CENTGENERS. THEORY OF BREEDING	NO. OF PLANTS STRAIGHT SELECTION.	NO. OF PLANTS HYBRIDS.	NO. OF PLANTS THEORY OF BREEDING	TOTAL NO. OF PLANTS IN NURSERY.
1897.....	56	40	75	5,600	4,000	75,000	17,100
1902.....	215	409	351	46,500	32,064	29,792	108,356
1907.....	102	378	299	10,600	56,055	55,691	122,346

important feature of the Minnesota wheat breeding is the method of distributing seed of the best varieties when they were ready for distribution. The most progressive farmers in various parts of the State were chosen as coöperators, and the seed actually sold to them in small lots at a price of $2 per bushel. This policy of placing a fairly high price on seeds of improved varieties was established in order to place the seed at the first distribution in the hands of men who recognized the value of improved varieties and were willing to pay for such seed. Again, it is found that when a farmer buys seed at a high price, and finds upon trial that the variety is more vigorous and productive than common varieties, he will usually take pains to keep the seed pure and free from foul weeds, and sell the seed to his neighbors at a price above the market price. Many farmers have thus built up a reputation for good seed, and have disposed of their entire crop each year at seed price; and, moreover, are able to sell the crop at the granary door.

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WORK AT THE NORTH DAKOTA EXPERIMENT STATION.

Professor J. H. Shepperd, in charge of the grain experiments at this station, has been closely associated with Professor Hays in all his breeding work, and has followed methods much similar to those employed at the Minnesota Station. Besides this fact Professor Hays himself was at one time in charge of the agricultural department of the North Dakota Station. Professor Shepperd has the following special statements to make concerning wheat breeding work at the North Dakota Station in recent years:

Something over two hundred names and doubtless a large number of distinct varieties have resulted from our efforts. Of these it is interesting to know that with the exception of one or two (records of which were destroyed by fire) they trace to the hard wheats of this community and to three individual farmers who had done considerable systematic breeding and sold good seed to their neighbors. With these as foundation stock for hard wheats, selection has been carried on in the nursery in addition to some cross breeding. Marked improvement has been made in tillering by reducing the number of late and small culms which spring up and hinder the development of the earlier and stronger ones, thus reducing their plumpness and grade in addition to supplying a mixture of small, inferior kernel, which further reduce the grade of the product from the individual plant and from the variety when it is grown in a larger way.

In a recent year of rust scourge we succeeded in selecting some very resistant strains, one of which came out as an apparent direct mutant.

The station took a prominent part in the introduction of the durum wheats in the drier districts of the State. The breeding work described for the bread wheats after eliminating the poorer varieties, is being duplicated with the durum strains. Changes have been made in the stooling and grade of wheat (durum) as mentioned above for the bread wheats. A change of seed of the same breeding showed a loss or disadvantage resulting.

The station has produced two varieties of wheat, two of oats—an early and a late sort—two of corn, two of potatoes and two of barley, which it has distributed very widely in the State. Our figures show 2462½ bushels of seed distributed to 945 people. We find that a large number of these grain growers who have received seed from this station have distributed large quantities of it in turn, thus giving it very wide dissemination. One man, for instance, who was a farmer, and not a seedsman, sent out 1821½ bushels of seed wheat of a strain which we put into his hands, to 29 people in a single season.

METHODS AT THE SOUTH DAKOTA AGRICULTURAL EXPERIMENT STATION.

At the South Dakota Experiment Station, where the wheat breeding work has heretofore been in charge of Prof. E. C. Chilcott, and later Prof. J. S. Cole, there is the unusual advantage of the presence of a very

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large number of varieties as a basis for work. The varied characters therefore of these many varieties and strains have furnished the experimenters at this place with an unusually thorough knowledge of individual plants. Various methods of adaptation and breeding work have been employed at this station concerning which Prof. J. S. Cole writes as follows; reference necessarily being made to work with oats and barley as well as with wheat, in order to compare methods used with these different cereals:

I have not yet found a method of handling breeding plats of either oats or barley that is satisfactory on our soil and with our climate. I cannot raise the progeny of single plants in either rows or centgeners and have them behave at all the same as similar varities do in the field. I have begun some definite experiments along this line, the results to date appearing to favor the "head-row" method.

We have not carried the hybridization of either oats or barley far enough yet to enable us to judge of its value with these crops. I do not, however, see much need of it for the reason that we get all the variation by straight selection that we need for our work at present.

With wheat both the "head-row" and "centgener" methods are quite satisfactory. The results check almost exactly between the two. The centgener method is the one by which most of our work has been done. I have made careful comparison, and find that the work can be done quicker by this method than it can by the row method. On the other hand, we think that the row system allows of closer comparison by observation than does the centgener. With either method we get a greater growth of straw, and a later maturity than we get from the same stocks in the field.

I am a strong advocate of straight selection for the bulk o the work that is calculated to result in the improvement of varieties. From a field of the best grain available select as many plants of marked individuality as you care to work with; plant these in rows or centgeners; throw away all but the few that are markedly superior to the others; increase these few for tests on a larger scale, and make new selections from the field every year when it is possible to make selections that appear to be of value. That, in brief, is the method that will produce results. It is not every year that superior plants or plants that possess any individuality can be selected from a variety. Some varieties are much more prolific of good plants than are others. Very often a change of soil or climate will break the type and the variety under the new conditions will afford a much richer field for selection than it did under the old. For example, I can get a much larger per cent of superior plants from Turkey winter wheat, or from S. D. Climax spring wheat by making my selections at Highmore from stocks that have there gone through several generations, than I can by making the selections at Brookings.

In selecting from fields I usually select single heads. This is merely a matter of convenience and safety with me. I had rather have a whole plant because of the larger amount of seed. Whether this seed shall be planted in a row or in a centgener is a matter of detail, that as I have indicated, I do not consider of prime importance.

We have in years past made many crosses within the strain, but they are all discarded now. Whether there is nothing in that line of work or whether it simply

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happened that we never worked with the right material, or never made exactly the right combination of individuals to get good results, I do not know.

We have not as yet obtained anything of value from wheat crosses with either spelt or emmer, but we still continue to make them.

Crosses between common wheat and durum wheat appear to be too radical. It takes a long time to get anything at all out of such crosses, and when a fixed type is obtained it is apt to prove of no value. As a result of such a cross I have a beardless durum that comes true to type, but I do not believe it is of any value.

As a result of all the crossing between varieties that has been done here I have one new wheat that promises to be of value. This year it doubled the yield of all other varieties of common wheat here, and at Highmore led our best varieties which were grown on each side of it by about five bushels per acre. It has a very strong, tall straw, is quite rust resistant, and is markedly different from any wheat I have ever seen. With this evidence before me I know there is some value in crossing between varieties. I do think, however, it should be done only with a definite object, in view, and only with a full knowledge of the characters and behavior of the varieties that are available for stocks.

I am making exensive use of hybridization in the effort to combine the milling qualities of our best common wheat with the rust resistance of emmer and G. I. No. 1736, Iumillo, and other durums. It may be impossible to make this combination, but I am convinced that there is no other way to attain the desired result. Rust resistance, whatever it may be, is something that does not exist in the common wheats; therefore, the only way it can be obtained is to breed it into them by hybridization. This example will serve as an illustration of the limitations of selection, and of the use of hybridization as I see them.

METHODS AT THE NEBRASKA EXPERIMENT STATION.

Prof. Alvin Keyser gives the following account of field methods in some especially thorough selection work, conducted with Turkey hard winter wheat:

First of all Professors Lyon and Montgomery's work with light and heavy seeds and light and heavy grain, carried on with wheat since 1899 shows that such a selection has not resulted in an improvement of the crop. Some recent experiments of Montgomery, the results of which are contained in a bulletin now in press, go to show the cause for lack of improvement by the selection of the heaviest grains. Montgomery showed that individual plants, as well as individual heads were made up of kernels of different absolute weight, and of different specific gravity, so that any selection based upon absolute weight or relative weight of kernels would not result in a change of hereditary lines to any marked extent. This also holds true in selecting large kernels, each plant and each head being made up of kernels of large and smaller size.

The breeding work was commenced here with 980-odd original selections. These original selections were made as follows: Good heads were chosen from the variety in the field; a portion of each head was taken for chemical analysis and the other portion planted by itself. The planting being made one seed in a place six inches apart each way, it was found that each one of these selections represented a different strain.

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There were sufficient differences between the progeny of each selection to be distinguishable in the field by a careful observer. These strains have been compared since 1902 when the experiments were started. It was found that some of these strains made a high, uniform average production—I may just as well say average performance. Some strains showed strong fluctuating variability, being good one year and poor the next. Other strains were uniformly poor. These remarks apply not only to yield but to the other qualities which we were considering. As you may know we were breeding especially for nitrogen content, and quality in the grain and yield, although other points, such as ability to stand erect, etc., were not overlooked. In making the selections this year, 1907, over 40 of these original 900 odd strains were tested in the field in $\frac{1}{80}$-acre plats, every third plat in the field being a check plat of the ordinary seed of the mother variety. These 40 odd strains uniformly showed a higher yield than the parent variety check plats. Practically the same thing was true of the nitrogen content, although this feature did not show the gain shown in yield. One very striking thing brought out is the uniform permanent excellence shown by certain strains, the uniform permanent lack of excellence shown by other strains, and the strong fluctuation shown by still other strains.

We have tried two methods of obtaining the original foundation stock. The first method consists of the selection of good heads from the field, in planting these heads in individual plats, giving the plants a uniform space. The other method consists of the selection from the field of good heads which were threshed out and made into one composite sample was planted in a full bed in the nursery, one seed in a place, giving each a uniform space. We have used 6 x 6 inches as the standard distance for all of our breeding work. Good plants were then selected from these full beds to become mothers of the centgeners. From my experience of the two methods of starting breeding work I prefer the first method given, viz: the selection of individual heads and planting the seed of these heads in individual plats, giving a uniform space to each. It seems to me that we gain at least one year's work by this method, and we are able at the same time to carry larger numbers, as there are sufficient plants in the first year of the work to permit of some comparison. Outside of the method of obtaining foundation stocks I would make no change from my present knowledge in our methods of handling and comparing the centgeners. Our work has shown that varieties are made up of exceedingly numerous strains and theoretically we ought to be able to pick out good ones at once, but in practice we find that it is not so easy. If we pick out five or ten good strains we may miss the best out of a hundred, but if we pick out forty good strains we will be almost certain to discover the good (best?) strains. The strains need to be compared with those of several seasons in order to eliminate the effect of fluctuating variations. After a number of years' comparison we can eliminate the less desirable strains with considerable certainty. By less desirable, of course, I mean to use this term in a broader sense so that it will include any or all of those qualities in which we may be striving to effect improvement.

In recent years Professor E. G. Montgomery has had charge of the continuation of the work just described, and has the following words to add with reference to their selections of this Turkey winter wheat:

Straight selections have been made from Turkey Red stock in the nursery similar to the system used by the Minnesota Experiment Station. Data have been kept

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each year of yield per plant, nitrogen content, rust resistance, quality of grain, size of head, etc., during the five years of selection. About 200,000 plants have been started in the nursery, from which selections have been made. Last year we had seed enough of about 130 strains of Turkey Red wheat, originated by selection to start a field test. A plat of $\frac{1}{30}$ acre was sown from each. As about 15 check plats were sown with these we hope to get results which will show something of comparative yields. We are also arranging to have milling and baking tests made. Also quite a number of crosses were made in 1903 and 1904 between a number of varieties of wheat growing here on the station farm. These have been carried along in the nursery breeding plats.

Some attention has been given to selection, and also attention was given to the working of Mendel's laws in wheat breeding. We still have most of these crosses growing in the nursery, but so far have not put any of them out in field tests. We also compare results obtained under nursery conditions to test the value of selection by ordinary nursery methods.

These statements were made by Mr. Montgomery in June, 1907, in connection with other correspondence, and were not intended to cover the ground fully. Since then the writer has visited that experiment station, after the crop of 1907 was harvested, and learned of a number of interesting things that have developed in the course of the work. A very interesting feature of the work is the great difference now observable between the different strains of Turkey wheat coming originally from single plants selected on the basis of nitrogen content out of the same original seed. Some of the plats stood up well, while others by the side of these were entirely fallen down. Some have yielded much better than others, and there are considerable differences in the head and other characters, in the plats of the different strains. The most important feature of the work is with respect to the very question of methods. While there were great differences among the different strains the greater proportion of nitrogen in some of these does not seem to continue constantly from year to year. The variation in character of the different seasons affects the different strains of wheat and appears to affect the different ones differently each year. By growing these strains in nursery beds or centgener plats it appears also that the plants in different parts of these plats are affected differently because of even slight differences of soil in different parts of the plat, so there arises the question whether more accurate results cannot be obtained by trials of these strains in rows, according to the row system, rather than by the centgener method. It has seemed highly desirable at this station to make trials of a number of these strains by both the row system and the centgener method.

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METHODS AT THE WYOMING EXPERIMENT STATION.

Professor B. C. Buffum, formerly Director of the Wyoming Experiment Station, has little to say concerning wheat breeding in that region, but writes as follows, very little of which has direct bearing upon the subject of methods:

I am not in possession of my notes, and can only give you a very brief idea of what has been done. You will remember that my wheat, oats and barley at the St. Louis Exposition outweighed other grains from any part of the world. The most of my work was with cereals, consisting of growing as many varieties as could be brought together, and selecting mother heads. I have for many years had a suspicion that there were many elemental species produced in a field in accordance with the new theory now advanced by DeVries. This is impressed upon one through observation of the marked variations which occur when seed from humid America is planted under irrigation. My new breeding work which is now being established commercially will be along the lines indicated by Nilson, DeVries and Burbank. While I accomplished what I consider rather remarkable results with old methods, I can see where much time has been lost. My varieties are all grown under number and I cannot give you names of those produced. When in Colorado I did some high altitude work in the San Luis Valley, which was afterwards finished by my assistant, Mr. Danielson, resulting in one variety of wheat, and one of oats, which have taken the place of almost all other grains grown in that region.

WHEAT BREEDING METHODS AT THE WASHINGTON EXPERIMENT STATION.

Mr. C. W. Lawrence, cerealist of this station, gives the following notes on "Methods of Investigation at the Washington Experiment Station:"

We have found by experience that the row system serves our general purpose much more satisfactorily than any other method yet tried. In order to retain a dust mulch in the drier area a space between the rows is absolutely necessary. Also in the case of hybrids this space enables one to make a safer and more thorough selection. The hybrids are maintained in the row from 4 to 7 years; though to secure the individual plants of a standard variety three years is the limit, while two years is more often the general practice. By continuing this row system from year to year and dealing with the plant as an individual it is possible to tabulate the exact records for future reference.

About eight hundred separate varieties of wheat have been tested by this station during the past few years. Quite a number of these have given satisfactory results for one or more seasons, and from them valuable foundation stocks have been started. A great many of these new, improved strains are introduced into the crosses or recrosses. By hybridizing we hope to strengthen the variety so that it may become of commercial importance, or that its strong characteristics may be transmitted to a hybrid more nearly like the other parent.

For convenience in keeping records three general divisions are made of the seed

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to be sown each season corresponding to the three following described methods of selection:

(1). *The harvesting of the individuals and treating the seed as bulk grain.* During the fall of 1904, fifteen strains (of 6 standard varieties common in the Palouse country) were started from head selections. The first two harvests more than half of these were rejected in the process of selection, though at the present time about 20 acres are growing as a result of this selection of choice heads in 1904.

This first plan was duplicated in 1905 with a result that more of the improved strains of standard varieties are ready for a field test. Both years these selections were made from winter wheats common to this Palouse country. At Ritzville in 1906, nine strains of Bluestem were harvested by the head selection mentioned above. The work was more extensive than with the winter wheats. The hot wave from the 3d to the 9th of July cut the growth of all the lower stools so that they remained short and matured little grain. Because of this condition it was an easy task to harvest the first heads to develop, and secure the best seed produced by the plant, yet this grain was not plump that season. The seed obtained by this process was sown during March, 1907, and at harvest produced 125 bushels of pure blue stem. Again this season 6 strains of Bluestem were harvested by the head selection method. This time only the best heads from each plant were saved. The amount of seed wheat obtained varied from 2 to 4 pounds, but the distance traveled to secure it covered quite a large area. This seed is to be sown and harvested as individual plants in the crop of 1908. From these numerous selections of standard varieties made during the past four years, a number of improved strains of the common wheats will doubtless be established within a short time.

(2).—*A. The selection of individual mother plants.* Five separate strains resulting from mother plants (one of the Russian winter wheats) are ready for a field test. Other selections are still maintained in the row, not being far enough along for the general field tests.

(2)—*B. The selection of a small per cent of the growing plants in either varieties or hybrids.* Where the variety is fixed it is the general practice to have seed in bulk from 15 to 25 per cent of the plants growing in the row. From this seed enough is sorted out to sow one or more rows the second year. At harvest from 25 to 40 per cent of the growing plants are threshed and later the seed is run through the fanning mill. From these pure strains obtained by two years' selection pure varieties may be started or seed sown in order to secure mother plants.

(3). *The selection of a head as a unit of a plant in either sports, varieties or hybrids.* In this selection we aim to secure scientific rather than practical results. Nearly fifteen hundred of these single heads are at present being maintained as individuals and many of them promise good results for the future.

The results obtained from the first hybrid work started by Professors Spillman and Elliot in 1899 were so promising that more extensive lines have been introduced About 600 crosses and recrosses have been made during the past nine years, and progeny of the majority of these is at present growing in the first, second, third fourth and fifth generations. These combinations represent crosses of hard and soft winter wheats; hard and soft spring wheats; hard winter and hard spring wheat soft winter and soft spring wheats, and quite a number of emmers and spelts introduced in both the winter and spring varieties. From this large number of crosses and recrosses we have learned many interesting and valuable points in plant breeding.

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METHODS AT THE CENTRAL EXPERIMENTAL FARM, OTTAWA, CANADA.

Dr. C. E. Saunders, cerealist in charge of the wheat breeding at the Central Experimental Farm of Ottawa, makes the following statements with reference to field methods on that farm:

A certain amount has been done in simple selection in an effort to improve standard varieties. In this work the method used has been somewhat similar to that commonly known as the "head-row" method, but the growing of rather large plats of each selected strain has in many cases been found necessary in order to determine the quality of the strain. Yield is by no means the only point to be considered in cereal growing, and in the case of wheat it is usually essential to perform milling and baking tests before any accurate idea of the value of each strain can be obtained.

In the production of new varieties in cross breeding it has generally been found best to secure parents having in one or the other of them all the desirable qualities which it was wished to combine. These varieties have then been crossed and the cross bred kernels sown a foot apart each way the next season.

Only in exceptional cases are any of these original plants rejected. The following year about one hundred seeds from each original cross-bred plant are usually sown, these being put in four inches apart each way in groups. From the plants so produced about 10 to 20 are usually selected at harvest time, taking those which possess, as far as can be judged, the desirable qualities. The seed from each of these plants is then rubbed out and compared with the product of the others, selections being then made for productiveness, plumpness, color, and in the case of wheat, for the gluten strength as judged by the chewing test. This second selection usually reduces the number of plants obtained to about one-half.

About fifty seeds from each of these are then sown in a separate group the next year. From each group a few plants are selected, these being re-selected as before during the winter and thus reduced to one or two plants for sowing the next season. This process is repeated until each group is found to be fixed in character, one plant from each of these fixed groups is then selected as a mother plant of the new variety and propagation is then carried on from this plant as rapidly as possible.

Of course during this process many groups have to be entirely rejected as otherwise the multiplication of them would be too great. Very often all the descendants of a particular cross may be rejected, and it seldom happens that more than three or four varieties are retained among the descendants of any one of the original cross-bred seed. When the propagation of the varieties is commenced they are as soon as possible grown under regular field conditions so that more satisfactory observations may be made on the strength of straw, etc. When a sufficient quantity of wheat is obtained for a milling and baking test, it is carried out, except in the rare cases where wheat is being grown for other than bread-making purposes. The determination of yield being so difficult and occupying so many years before trustworthy conclusions can be drawn, is postponed until all the other characteristics of the variety are established, but of course, vigor and apparent yield are used as a basis for selection from the very beginning.

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METHODS OF BREEDING WHEAT AT THE ONTARIO AGRICULTURAL COLLEGE, GUELPH, CANADA.

Professor C. A. Zavitz, who has charge of the work of field husbandry at the Ontario Agricultural College, has furnished the following concise statement regarding the methods adopted in wheat breeding at that Institution:

In order to become as familiar as possible with the leading varieties of wheats in cultivation in different parts of the world, about four hundred distinct kinds have been secured from various sources and have been carefully tested in field plots. Each of these varieties have been grown for at least five years, and some of them for a much longer period of time. In order to get the types as pure as possible, both the seeds and the growing plants are examined, and only those which are true to type are allowed to remain. Careful notes are taken each year in regard to the length of straw, the strength of straw, the amount of rust, the amount of smut, the yield of grain, the weight per measured bushel, and more recently to the milling and the bread producing qualities, etc.

Efforts have been made to improve some of the best varieties through continuous and systematic selection. Selections have been made of the Dawson's Golden Chaff, Imperial Amber, Bulgarian, and Turkey Red varieties of winter wheat, and of Red Fife spring wheat and also from the Wild Goose and Medeah varieties of durum wheat, and of the Common Emmer. Some of these selections have been made from choice heads obtained from the large fields, and others from amongst about 9000 plants of each variety which were in rows one foot apart, in which the plants were one link apart in the rows. The selected plants which furnished the best quality of seed were planted in rows in the following year. Those strains which produced the best results in the rows were used for both rows and small plots in the year following. In the next succeeding year, the strains which gave the best results in the rows and in the small plots were sown again in rows and in small plots, and also in plots larger in size and similar to those used in the regular variety work. In the average last three years, the best selected strain has surpassed the original variety by 10.4 bushels per acre in the case of the Dawson's Golden Chaff, and 4.7 bushels per acre in the case of the Turkey Red variety.

With the object of combining the good qualities and eliminating the undesirable characteristics, work in hybridization was started in 1902 and has continued each year since that date. Crosses have been made between the Dawsons Golden Chaff and the Turkey Red, the Bulgarian, Tasmania Red, Buda Pesth, Geneva and Imperial Amber varieties of winter wheat; between the Bulgarian and the Turkey Red varieties of winter wheat; between the Red Fife spring wheat and the Turkey Red winter wheat; the Herison bearded spring wheat, the Wild Goose, and the Medeah durum wheats and the Common Emmer. In 1908, there were 412 row plots of wheat hybrids, each containing one hundred plants. There were also sixty small plots and nine larger plots of those hybrids which were fixed in most characteristics. The results of part of the work is somewhat discouraging, but those of other parts of the work are very promising.

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METHODS PRACTICED BY THE OFFICE OF GRAIN INVESTIGATIONS, BUREAU OF PLANT INDUSTRY.

A large number of varieties of wheat were obtained from all parts of the world and planted in 1895, before the organization of the Bureau of Plant Industry. This was done primarily to secure if possible varieties that are resistant to rust, no breeding to secure other qualities being thought of at that time. Later, in 1900, from the stock of varieties obtained and grown up to that date a number of the best ones were selected, and about 200 crosses were made, this work being done at Halstead, Kansas. The next year it was impossible to get land for the experimental work at this point and the seed resulting from the crosses of the previous year were divided into two equal parts in every case and a full series of half the seed of all crosses was planted at College Park, Md., in coöperation with the State experiment station at that place. The other half of the seed of all the crosses was reserved until the following year, 1902, and planted in Kansas. These crosses were kept under cultivation for a number of years, several different selections being made from the progeny of each cross each year at the two different points in Maryland and Kansas until of course a very large number of these new hybrid wheats were obtained, and from these finally a few have been selected that are of unusual value in regard to certain qualities; for example, rust resistance, resistance to drouth, yield, winter hardiness, etc.

The important thing, however, that was learned during all this work for a number of years is that in the case of our own work—and we infer most likely in that of the work of many others in this country—the operations of actual wheat breeding were begun before we had a sufficient knowledge of varieties. In the meantime many more varieties have been obtained from different countries and also from remote parts of this country and from India and Mexico and the association with these different kinds, and observations made upon them in the field at many points, has given a large amount of information concerning wheat varieties, their relation to each other and their adaptations to different soils and climates. Now the whole subject of wheat breeding has come to be a much more simple matter and much easier one to handle and can be pursued with much more certainty of getting definite practical results. From this experience, it seems to us no question but that three or four times the amount of gain resulting from the wheat breeding practiced to date in this country could have been obtained much more easily and in a fraction of the time by securing certain varieties of

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wheat already existing but which were not known to us at that time. To give an example: Efforts have been made not only by us but by experiment stations to increase the yield of the hard winter wheat through selection. In 1900 this department introduced the Kharkof wheat from north central Russia, which is practically an unusually hard strain of the Turkey wheat. This on trial in this country gave at once a yield of 3 to 5 bushels per acre more than the common Turkey winter already grown here, this increase in yield being several times greater than had yet been obtained by any process of selection carried on through several years. Before that time we had tried to obtain such improvement by selection without knowing of the existence of the Kharkof wheat. The same thing is true to a much greater degree in the case of the durum wheats. After trying to produce varieties better adapted to the dry districts of the Great Plains, we found, on introducing the durum wheats into this country in 1900, that yields could be obtained from these varieties from 30 to 50 per cent greater per acre than that of the best other dry winter wheats then known. It requires at least about seven years to produce a new variety by cross-breeding and selection, or by simple selection, but these extremely drouth resistant durums were obtained and established inside of about three years. As a matter of fact, we had a good idea of the adaptation of the durums before they introduced in large quantities from our nursery trials of such wheat years before. As stated, all this experience in the adaptation work with different wheats shows conclusively that a man or an institution is in no condition for carrying out accurate breeding work with wheats until there is at hand a rather thorough knowledge of a very large number of the different known varieties of this cereal from various portions of the world.

In addition to the important fact just emphasized, in the study of the numerous varieties there are many other things of lesser importance learned that are of the greatest advantage. In the first place of course a man becomes very skillful in detecting different qualities in comparing one wheat with another, after such an experience in the study of varieties for many years, so that he is very much better prepared, in a general way, to conduct breeding experiments. He soon learns also that the superiority of one variety of grain over another depends on a large number of different things, and that if one variety shows itself to be better than another at any one point, it may be true at the same time that this variety may not be as good as the other at some other point, because of the fact that one kind of climate or soil is favorable to one strain of

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wheat, while a different kind of climate or soil would be required to favor another strain. This leads naturally then to the conclusion, which is a very accurate one, that all improvement of wheat should be made exactly in the locality as nearly as possible where the wheat is afterward to be used.

Even in work conducted in a single state of the size of 60 to 100,000 square miles, the results obtained in wheat breeding at the main experiment station can hardly be depended upon to hold good at some other remote part of the state. Wheat hybrids that are fixed at the state experiment station have to be tested in other parts of the state along with other standard varieties for two or three years to be actually certain of their value at these points.

Another thing that has been learned at the experience already mentioned with many varieties obtained in the operations of this office is that it is very unwise to be hasty in discarding a variety or strain. A number of years ago, in the course of work carried on in coöperation with the South Dakota Experiment Station, at Brookings ings, it was decided, after four or five years' trial, that the variety Ghirka Spring was of little or no value, and it was thought well at the time to discard it. Simply to give it a further chance, however the variety was retained for a while longer. Later, on transferring the strain to other and dryer portions of the state, it was found that after two or three more years' trial that it stood actually at the head of all the varieties of that wheat group grown at those points farther west, it having even exceeded in yield and hardiness a number of the pedigree varieties of the common group. Naturally therefore, there has been no further disposition to discard this variety; in fact, it is being exploited at different places in South Dakota now as one of the best wheat varieties of the common group. In other cases certain varieties of wheat like the Chul from Turkestan, though proving to be of no use at all in many parts of the country, have later been found to be well adapted to certain restricted areas. Chul, for example, seems to be a very good wheat for southern California or Arizona, if not one of the best.

These are statements of a general nature as to the actual field operations. We have long ago adopted the practice of dividing the field work into three groups as regards the space employed: the nursery work, the small plat work, and the field plantings. Every new introduced variety or new hybrid is put first into the nursery or row planting. After at least three years in the nursery, if it is found to be very good in comparison with a large number of other kinds, it is transferred to the increase

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plat, and then later, when there is sufficient seed obtained, to the tenth acre plat. There are usually from 10 to 50 varieties carried each year at each of the experimental farms in tenth-acre plats. After two or three years trial in the tenth-acre plats, the still smaller number that are considered the very best are put into field plats each of an acre or more. Here they meet with practically the same conditions that are obtained in the field on any ordinary farm.

PURITY OF TYPE.

Another important thing not mentioned, which is soon learned in many years' experience with numerous varieties, is the fact brought out by De Vries in recent years that every commonly known variety of wheat or other grain is made up of numerous sub-varieties or strains, which De Vries himself erroneously calls elementary species. Aside from this fact, in almost all introduced wheats, and especially in many obtained from the farms in this country, there are actually mixtures of other varieties and even of varieties from other distinct groups of wheat. The first thing therefore that must be done to conduct any intelligent breeding operations is to purify the variety to be employed. This too is rather a tedious process. For several years much time has been given in the work of this office to the production of pure types, in which the different important kinds have been separated into a number of strains of from 2 to 20 in every case, originating from a single mother plant. While we have probably not done this work in the same manner, it virtually results in securing the same pure strains that have been obtained through the work of Nilsson at Svalöf. To make a certain cross or begin a considerable selection without purifying the strain in this manner means that one may happen to choose the individuals for parents that do not represent the type at all or they may be quite inferior to the type of the variety and therefore the work is conducted blindly.

As a basis for the nursery work, it should be stated that in this office we have employed constantly the row method, in contradistinction to the centgener method. After many years' experience, I still think this to be the best general method of conducting nursery work. The centgener method, however, has not been entirely excluded but has been employed in a number of instances, particularly in the multiplication of progeny of certain purified types or selections from wheat hybrids. That is to say, we have found that there are instances in which it may be advisable to use the centgener method. There are several reasons why the row

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method has seemed to give better results. One is that in planting by the row method, we get nearer to actual field conditions and therefore conclusions as to the value of a new variety seem to be better founded. Planting in the row at 8 to 12 inches apart imitates very closely the field planting with a drill. In order to carry out this idea more fully, we have even practiced the method in some cases of planting certain new strains at two rates of seeding, side by side in the nursery; i. e., one row would be planted at 4 to 6 inches apart in the row, giving similar spacing as that employed in the centgener method, and another row would be planted at the usual thickness of drilling wheat in the field, so that we begin very early in the history of the new strain to obtain natural comparisons of yields and other qualities on a field basis.

Another advantage of the row method is that if the ground is at all nonuniform or if there are slopes or inequalities, the rows, if of sufficient length, can be run entirely across all of these irregularities, while in the case of the centgener plot, being square, it would have the apex of one portion of this area only, and the next centgener would have to lie in a different portion of the area where the conditions may be considerably different, and therefore it would be unfair to compare the two centgeners. At some experiment stations the irregularities of the contour and of the composition of the soil may be so great even in a very small space as to make this question a very serious one. Another advantage claimed by a number of workers in using the row system is that in the centgener method, as commonly practiced, too much stress is laid at the beginning on the productive power of a single plant, while it seems better to select instead of a single plant, a number of the best plants from the progeny of this single plant as a basis for further comparison.

DUPLICATING THE TESTS.

One feature that we have emphasized in all field tests of new strains that may be of interest to others is the testing of each of these strains in several duplicate plats, putting each plat under a different cultural method or a different date and rate of planting. So much depends on these matters that it hardly seems proper to draw conclusions from variety tests that are made uniformly under only one of these conditions.

Different varieties may behave differently, and as a matter of fact do under different cultural methods. A good example of this kind was discovered recently in experiments in the Texas Panhandle, where it was found that the durum wheats as a rule gave much better results on spring

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plowing while the common winter wheat varieties did much better on fall plowing, other conditions all being the same.

SUBJECTION TO EXTREME CONDITIONS.

It is often attempted to develop varieties that are resistant to rust or resistant to drouth or that are hardier through the winter than other common sorts. It would seem natural that the very best strains for such purposes can be obtained if they are subjected to the most severe conditions in every case, but as a matter of fact, it is seldom that this is done. In recent years we have made it a practice to follow this plan. In some instances, for example at the experimental farms on the Plains, it is a common thing to grow some of our most promising sorts in such a way that they are forced to receive the least amount of water possible. Instead of giving them good cultural methods and cultivating with the purpose of conserving the moisture, every effort is made to keep the moisture away from them. At the same time in order not to lose the strain, a small amount of seed is sown under better conditions. Through this exposure to very severe conditions, much hardier and more vigorous individuals are secured, and it is certain that we have gained a great deal in adopting this practice.

GENERAL CONCLUSIONS.

It is seen from the study of the foregoing statements from different workers that there is a great diversity of opinion and practice in regard to field methods. This fact is due to several causes:

(1) The individuality of the workers. No two men get exactly the same ideas even from the same experience.

(2) The particular purpose in view by the person doing the work.

(3) The variations in soil and climate in different portions of the country make it impossible to conduct the same methods as to planting, cultivating, etc. There appear to be, however, certain practices that are common to almost all the experimenters, and at the same time there are certain facts in regard to wheat breeding which would probably be accepted by nearly all of these men. It will no doubt be an advantage to summarize here the conclusions that are thus generally applicable to all instances, with all experimenters.

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GENERAL PRINCIPLES.

(1) No one is really competent to get the best results from wheat breeding until he has given from three to five years' time to a thorough study of many of the wheat varieties, and particularly representatives of the different wheat groups, both in the laboratory and in the field, but particularly in the field.

(2) The preceding statement has reference particularly to the skill of the operator. At the same time it is necessary to get together the different wheats from all parts of the world, in order to be sure that one has a good foundation for his future work in selection and cross-breeding.

(3) The truth of the foregoing propositions is evident from the fact that much of the so-called wheat breeding today is simply a sorting of types from mixtures of strains already under cultivation, there being, as a matter of fact, no genuine variety in existence except the very few that have already been developed from single plants (mother). This sorting out or development of pure types is of course not accurately breeding but simply a separation into pure elementary strains.

(4) After several years' work in selecting and hybridizing, different experimenters have found that they will gain a great deal by finally doing what should have been done at first, i. e., developing pure types from the different so-called varieties they are using for foundation stocks. This is now being done at a number of experiment stations and in the Bureau of Plant Industry in the U. S. Department of Agriculture.

FOUNDATION STOCK.

(5) After the separation of elementary strains, the very important subject of the selection of foundation stock for future breeding is next in order. Different men will have different purposes in view, depending on the locality, and of course the selection of individuals for future breeding will depend on what is especially desired. For example, for rust resistance one needs to select out of many individuals—from 100 to 500—those that have so far resisted rust most strongly. While the particular character desired is kept in view, it should be noted that it is all the better if these individuals have other good qualities, as for instance productiveness, resistance to cold, etc.

(6) In this various sorting of types and selection of foundation stock, much headway will of course be obtained and individuals will already be found that are much better than others, so that one begins at once with an improvement.

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(7) After all, natural selection is the most certain, and it is important always to take advantage of severe rust seasons, if one is selecting for rust resistance, or severe seasons of drouth, if one is selecting for drouth resistance, etc., choosing those individuals that have passed through these seasons with the least injury; in fact, man's selection is simply following and taking advantage of nature's operations.

(8) In order to obtain the very best individual plants for foundation stock, it is often an advantage to expose quite a number of good plants to severe conditions. This has been practiced by a number of experimenters. For example: 200 or 300 plants of a strain of wheat already rather drouth resistant are planted under conditions where they will receive the least amount of moisture possible, and no cultivation is given them to help in conserving moisture. Evidently the individual plants that survive through such treatment as this will be exceedingly resistant to drouth. This particular practice has been followed in the Bureau of Plant Industry. Professor H. L. Bolley, of the North Dakota Experiment Station, has followed the same practice with regard to rust resistance.

(9) After choosing the foundation stock, simple selection is virtually a continuation of the same practice. The next year after this stock is planted, the best individuals may be selected in the same manner and operations continued thus from year to year.

NURSERY WORK.

(10) There are two general methods of treatment of selected strains in the nursery: one is the planting in centgener plots; the other is the row system.

(11) The concensus of opinion from different workers appears to be to the effect that as a rule the best satisfaction is obtained from the row systems, although centgener plantings are practiced by nearly everyone, and may be the best for particular cases.

(12) In the row system there is the advantage of growing the strain or hybrid under practically the same conditions as in the field, which enables us to make more accurate comparison between the results thus obtained with these improved strains and those obtained with standard sorts on the farm.

(13) To get this comparison most accurately, however, it is necessary to plant the seed at the same rate of seeding as in farm practice, and this does not allow a thorough study of individual plants, as one is unable then to separate them.

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(14) It is therefore advantageous to plant each selection in two rows, side by side, in one row the planting being at the rate of seeding on the farm, and in the other at a distance of 4 to 6 inches apart in the row.

(15) A criticism of some made on the centgener plan is that one is unable to select the best individuals from a sufficient number of original plants. This criticism, however, appears not to be very well founded. It is not exactly a criticism of the centgener principle but simply means that always one should make his selection as widely as possible from a great many individuals, which can be done under the centgener as well as the row system.

(16) At a number of places a common practice is the head-to-row method, in which seed of the best heads, selected out of a certain plat of wheat, is planted, the seed of each head in a distinct row—practically the same as the ear-to-row method in corn selection.

(17) It is claimed by advocates of this method that one obtains very quickly the good results following from selections from a number of plants the same season instead of starting with a single mother plant.

(18) One note of importance made on this last method is that while it appears to bring very good results, it would be more accurate if the *plant* were taken as a unit instead of the head, and all the grains of *one plant* seeded in a single *row*.

HYBRIDIZATION.

(19) The general opinion of the different experimenters is that there is after all little gained from our work so far in hybridization, although there is no doubt much advantage in making occasional careful crosses.

(20) As in the case of selection work, it is of the greatest importance to start with the very best individuals obtained after several years' sorting.

(21) It is extremely important to have a very definite idea in making crosses and to follow that idea rigidly. For example, one may have a very high yielding wheat but with rust resistance. This wheat should therefore be crossed with a variety that is very rust resistant, and an effort should be made to hold those two qualties in the offspring. It may take several years and many selections of the offspring to do this, but keep this rigidly in mind and allow nothing to sidetrack the experimenter.

(22) As the chief thing in hybridizing is to create a large amount of variation, it is naturally advantageous to practice composite crossing, i. e., before a hybrid has been fixed, cross it with some other good variety, even from a different wheat group if practicable, and the resulting

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hybrid with still another variety, etc. From the great many variations thus produced, one has a greater chance of obtaining what he wishes.

(23) The emmers hold the chaff. It is therefore important to cross with emmers to prevent shattering.

(24) The most rust resistant wheats in the world are the durums. Durums therefore should be used in crosses to develop rust resistance.

(25) Durum wheats and emmers can be used to great advantage also in crosses for the development of drouth resistance.

DISCARDING.

(26) The discarding of strains supposed to be of no value to the locality is a very serious matter, and from the experience of many workers, it is certain that no discarding should be done short of three years' trial.

(27) It is especially important to know that a variety or strain that has been found to be of no value even in a number of localities may afterwards prove the very best for some other district. This should therefore be kept in mind and certain strains that appear to be of little value should be kept for planting at still other points where they may prove to be well adapted. As an example, the Chul wheat may be cited: this appears to be of no use whatever for any portion of the United States except southern California, Arizona, New Mexico and a part of Texas.

REPORT OF THE COMMITTEE ON BREEDING WILD MAMMALS

PROGRESS IN PROPAGATING DEER.

By D. E. LANTZ, *Chairman, Washington, D. C.*

At the last meeting of the American Breeders' Association the Committee on Breeding Wild Mammals submitted a report on domesticating and propagating big game animals, recommending especially the Virginia deer and the round-horned elk, as adapted for venison production in the United States. Since that report was made considerable interest has been aroused in breeding deer for venison. The Department of Agriculture, some five months ago, issued a short Farmers' Bulletin on Raising Deer and Elk, which is having wide circulation.

An attempt is being made by the department, through the Biological Survey, to secure a complete list of the deer parks and big game preserves now in existence in this country, together with the numbers of animals they contain. It has been discovered that the number of breeders of

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