BREEDING DROUTH-RESISTING CROPS.

By ROBERT GAUSS, *Denver, Col.*

The most eastern part of the arid region forms the western part of the Great Plains, known to geographers of two generations ago as "the Great American Desert" and including part of the country to which Webster so unwisely referred in slighting terms as "our Asia." The area in question extends from the Mexican border on the Rio Grande northward along the eastern base of the Rocky Mountain foothills far into the British possessions, where finally the snow and cold of the sub-arctic region introduces a new desert factor and make agriculture under any conditions of moisture impracticable. This region follows the course of the mountains retreating eastward in Colorado, and then swinging so far to the west in Montana that nearly the whole of that State is embraced within its limits. Possessing an average width of nearly 300 miles, it constitutes in the aggregate a country of vast area, that part of it which lies within the United States exceeding in square miles either France or Germany. It constitutes the most interesting part of the grassy plains, receiving precipitation enough to maintain a strong growth of perennial grasses, but lacking as a rule an adequate supply of moisture to make the profitable production of cereals and other annuals practicable. In eastern Colorado the normal annual precipitation is about 14.50 inches, from which there is but little departure either north or south of the State. About two-thirds of this precipitation occurs between March 1 and September 1, thus coming in the growing season and at a time when it can do the most good. Occasionally in exceptionally favorable seasons like that of 1905, agriculture is practicable without irrigation. But upon such seasons little dependence can be placed, and hence, where irrigation is impracticable, farming must remain a precarious industry unless means be found to adapt not physical conditions to vegetation (as through irrigation) but rather vegetation to physical conditions through acclimatization of desirable species.

It was in the latter part of 1886 that the idea first occurred to me that something might be accomplished of practicable value to arid-region agriculture along the lines just suggested. It found expression in an editorial printed in the *Denver Republican* of November 21, 1886, entitled "Is There an Arid Region," and in which the following suggestion appeared:

There is, of course, a limit beyond which we cannot go in reducing the quantity of moisture essential to vegetation. But within the limits of reason we may say that nature accommodates each vegetable organism to the conditions which surround it. We may by sowing seeds in a moist soil and by keeping the soil in a moist condition, develop in a few years a plant which could not thrive without a great deal of moisture; and we may with seeds taken from the same plant as the others, develop in the same time, by the contrary process, a plant which would require but little moisture. It may be possible, therefore, by a series of experiments extending through several years to develop a variety of wheat or other grain which would thrive on our highlands without irrigation. Until it is proved that all such experiments would fail, we must admit that it is an open question whether this is or is not an arid region.

At intervals thereafter, I repeated this suggestion, and for a time I induced a farmer of my acquaintance to conduct experiments along these lines, which, however, were abandoned before notable results were achieved. It was not until the spring of 1896 that I undertook the experiments myself. In doing so I was much encouraged by a conversation with Mr. W. M. Hays, now secretary of the American Breeders' Association and Assistant Secretary of Agriculture, who recognized that there was ground to hope that something might be accomplished. I recall that I told him that among the plant characteristics I should note in selecting wheat grains for replanting would be amount of leaf surface, size of head, and size of root, and that he remarked that it would be hard to make observations of any value respecting the roots of wheat plants. Subsequently, finding this to be true, I accepted the outward appearance of each plant as sufficient evidence of the size and strength of the roots.

I recognize that so far as this convention has any desire to hear from me at all it is in respect to what I have accomplished and the methods employed. Unfortunately I have accomplished so little of a definite character, and the methods employed have been so simple that there is really very little for me to tell. Prof. Olin of the Colorado Agricultural College kindly wrote me some months ago that in his opinion my experiments had demonstrated that it is practicable to increase the drought-resisting power of cereals by breeding. That, probably, is about all that I can thus far claim to have done. Although my personal experiments indicate that the particular variety of wheat I have developed is more drought-resistant than any of the other varieties planted by me, the same result does not seem to have been secured by all persons to whom I have sent seed. Prof. Olin tells me that the milling qualities of my wheat are inferior to those of some other varieties tested by him; and there seems to be no question that at places where it was tested on the plains last summer my wheat was more subject to attacks of rust than the varieties near which it was grown. Therefore, it would be premature for any one to conclude that I have solved the entire problem of acclimatizing cereals to arid conditions. If I may justly lay claim to have pointed the way by which a solution may be reached, I shall be satisfied, even though I may have to leave to others the full demonstration of the theory.

I began my experiment in the spring of 1896 with wheat of the variety known as Improved Fife, which was sent me from the agricultural college at Fort Collins. The ground was broken that spring to a depth of about 7 inches and the seed was sown broadcast. The season was extremely dry and I obtained only a very small quantity of seed. It was sufficient, however, for replanting as extensively as I desired in the following season of 1897. In the last named year I adopted the plan of placing single grains at intervals of 12 inches each way, thus giving one plant to each square foot. It was a tedious process, but it enabled me to select my plants with more care. Each year since then I have repeated this method of planting. For several years I broke the ground to a depth of from 14 to 16 inches, using for this

purpose a subsoil plough. I also caused the surface of the soil to be broken with a hoe, thus producing a loose mulch for the purpose of preventing evaporation. Subsequently I abandoned both these methods, lest by the result attained I should deceive myself. I was convinced that in practical farming few men would subsoil their ground and that none would be induced by any promise of bountiful crops to keep the surface broken in order to prevent the loss of moisture by evaporation. In short, I wished my wheat to be subject to as adverse conditions as it would be subjected to in practical farming, thus assuring myself that whatever results I might attain would at least not be deceptive. In 1897, I enlarged my experiment by adding oats and beardless, or stock-feeding barley. In 1898 I added rye; and in 1903 I planted for the first time four varieties of durum wheat and one soft wheat, known as Fretes, sent me by Mr. Carleton of the department of agriculture. The durum wheats consisted of Kubanka, Pelissier, and two kinds of Kahla. In the same year, 1903, I added Turkestan alfalfa, on the theory that I should acclimatize a leguminous plant which in rotation would restore the fertility of the soil. In 1904 I added Red Russian wheat the seed for which was obtained from Logan County, Colorado, on the plains, and a variety of malting barley called Saale, the seed having been obtained from Mr. Altenbrand of Manhattan, Montana, who had imported the original seed from Germany. In addition to the foregoing, my experiment includes sugar beets, potatoes, and field peas, but too little time has elapsed to determine whether there is much promise of success with these.

Last spring I planted most of the cereals in beds of 20 rows a foot apart and 100 feet long, thus giving, theoretically, 2,000 plants, each occupying the space of one square foot. This is theoretical only, however, for at least 20 per cent of the places are as a rule unoccupied. My own wheat was planted at the rate of one plant to the square foot in rows 100 feet long, but in this case there were 80 rows instead of twenty. The ground was broken in the spring about 7 inches deep, but not subsoiled. No fertilizing material was used. The soil where these experiments were conducted is thin and contains a little sand, but in respect to fertility it is much poorer than the average soil in the vicinity of Denver. These grains were planted during the last week of March, and except to cut out the weeds nothing further was done to them until they were harvested between August 2 and August 10. There was, of course, no irrigation; but the season was abnormally wet, the excess occurring between March 1 and May 1. After the last named date it was slightly below normal in this locality, although in some parts of the plains region it continued to be excessive until late in the season.

In considering the yield of these different varieties and species it should be observed that since there was at most only one plant to the square foot, the test is no measure of what might have been obtained by thicker planting and a closer growth. I am convinced, however, that to obtain the best results with wheat of a small grain, such as mine is, it should not be sown thicker than half a bushel to the acre. Thicker seeding would check stooling and make too great a

drain upon the supply of moisture in the soil. The yield of each variety was as follows:

	Pounds.
8522 Kubanka, 20 rows 100 feet long	21
7581 Kahla, 20 rows 100 feet long	24
7794 Kahla, 20 rows 100 feet long	29½
7785 Pelissier, 20 rows 100 feet long	31
7582 Fretes 20 rows 95 feet long	24½
Red Russian, 20 rows 100 feet long	27½
My Wheat from selected grains, 80 rows 100 feet long	143½
Saale Barley, 20 rows 100 feet long	13½
Beardless Barley, 20 rows 95 feet long	21½
Rye, 20 rows 95 feet long	23½

The foregoing amounts may seem small, but it should be borne in mind that the seeding was at the rate of one plant to the square foot. It will be observed that the yield of my wheat was notably in excess of the best of the others. The 80 rows of my wheat a foot apart and each 100 feet long occupied something less than one-fifth of an acre. Thus it will be seen that the yield was at the rate of about 13 bushels to the acre, with only one plant to the square foot. The Kubanka for some reason gave less a satisfactory yield than any of the other durums, although it is commonly considered the best of those varieties. The estimate which places Kubanka in the lead among durum wheats is in my opinion correct, notwithstanding the poor showing it made in my experiments last year.

Professor Olin of the Colorado Agricultural College writes me that Kubanka seed planted alongside mine on the college farm gave a notably heavier yield than mine. But none of the tests made last year were of much value for the reason that the precipitation was abnormally great. I may add, however, that Professor Olin also wrote me that he planted some of my wheat a few miles south of Pueblo in what he said was the driest seed bed into which he had ever been guilty of putting seed, and that notwithstanding the season was dry in that locality and oats and barley planted in proximity to my wheat perished for lack of moisture, mine remained green and matured its seed in a normal way. This difference in results he attributed to the greater drought-resistant power of my wheat, acquired through breeding or acclimatization.

My whole theory is based, of course, upon the presumption that the plants which in growth and maturity reveal the greatest power to resist drought will transmit that constitutional difference to their offspring. Hence by taking advantage of this variation I have endeavored to perpetuate and emphasize the drought-resistant qualities. I have gone on the theory that the vegetative will be sacrificed for the sake of the reproductive processes of the species, and that an acclimatized variety of wheat will consequently have a small leaf surface, a short stem and a relatively large head. This theory seems to have been borne out by results in the course of my experiments. It may be said that the path of acclimatization lies through deterioration, as a result of which an acclimatized variety will present a stunted appearance, and to a person not informed in regard to these conditions, its

yield will be far in excess of its promise. One should not conclude, however, that poor vegetative development is in itself a thing to be sought or desired. On the contrary in selecting seed for replanting regard should be paid to the vegetative as well as the reproductive development of the plant. So far as practicable, seed should be chosen from plants showing not in one alone, but in all respects, the most vigorous development. Thus it may be that better results will be obtained from seed taken from an evenly developed and vigorous plant rather than from one containing a single large head but with poor development in other respects. Observing this, I took care last summer to select for this year's planting seed from a number of plants which had almost a bushy appearance, so closely crowded were leaves and stems. The heads as a rule on these plants were not extraordinarily large, but the fact that they numbered from 34 to 39 on a plant, made seed from them desirable. I note also the character of the leaf or blade, whether it is broad or narrow and whether it is thin and delicate or thick and coarse. Theoretically, the latter would seem to be the more drought-resistant, but I can not state that this has been established by my experiments.

Observation indicates that a variety of wheat acclimatized to arid conditions will be relatively light in weight and that it will have small grains. The natural tendency seems to be to multiply the number of seed whenever a species is contending against adverse conditions, and associated with this is a tendency to make all the seeds small. Although small, they may, however, possess exceptionally great vitality, and this, in fact, seems to be true of the grains of my wheat. To what degree a cereal acclimatized to aridity will be structurally different from one adapted to humid conditions, presents a problem which awaits solution in the future, and I may add that in my opinion it is one of the most interesting to which experimental botany in the arid region can give attention. That perfect acclimatization demands this structural difference in order that the species may not only survive but yield a bountiful product under conditions of greatly reduced moisture seems to be clear. Hence from the list of perfectly acclimatized plants I should be disposed to exclude some of those annuals, which, although growing in the arid region, manage to survive only by taking advantage of seasonal rains which temporarily establish humid, as distinguished from arid conditions. In an essay on the "The Ecological Relations of the Vegetation of Western Texas," Mr. William Bray speaks of a growth of prairie annuals which he declared to be "mostly pure mesophytes." In regard to these annuals he used the following language:

The species of these formations are of course dependent upon seed for their recurrence, and consequently are subject wholly to the caprice of rainfall during March and early April. When, as frequently happens, there is no rainfall of consequence during this period, the display of prairie annuals is very much reduced. Their adaptations are in the direction of seasonal adjustment rather than toward meeting xerophytic conditions.

It is this seasonal adjustment as distinguished from adaptation to xerophytic conditions which in my opinion should exclude all such

annuals from the class of species fully acclimatized to arid conditions. This inquiry acquires practical value from the fact that while seasonal adjustment of the kind just mentioned may suffice to produce seed enough to perpetuate a species, it may not produce enough to make agriculture a profitable industry. What I aim at, therefore, is the development of a variety which, structurally, will be so constituted that its adaptations will not be in the direction of seasonal adjustment, but rather "toward meeting xerophytic conditions."

Desiring to obtain the opinion of a botanist of acknowledged ability in regard to whether the development of annuals with distinct adaptation to meeting xerophytic conditions might be considered practicable, I wrote last summer to Professor Frederick V. Coville, Botanist of the Department of Agriculture. In answer I received from him an exceedingly interesting letter dated July 31, 1905, from which I take the liberty of making the following quotation:

It is undoubtedly true that desert annuals are not in general equipped for a small amount of transpiration. Indeed, when you consider the conditions under which these annuals are placed you will see that it is necessarily to their advantage to transpire as great an amount of water as possible, for while they temporarily have plenty of water from one or more rains, this supply of water does not last very long. You are doubtless familiar with the general law that *other conditions being equal the vegetative growth of a plant is proportional to its transpiration.*

I wish to point out that the transpiration of desert shrubs is not uniformly small. While their transpiration is exceedingly limited during the dry season, it jumps up enormously when the rains come. I have not the exact measurements of transpiration which have been made at the Desert Laboratory, and which are now in the hands of the publishers, but my impression is that when the supply of water is abundant the transpiration of the creosote bush, *Covillea tridentata*, is more than 20 times as great as in the dry season. What these plants possess, and what you need to secure in your breeding experiments with annuals, is the greatest amount of elasticity in transpiration ability. You want a plant which will transpire when water is abundant just as much moisture as possible, so that its growth may be as great as possible, but one which, nevertheless, if a part of the season, or if the whole season happens to be unusually dry will live through and produce something of a crop.

I am not prepared to assent to a rigid adherence to the proposition that 276 pounds of water must be provided for the manufacture of one pound of dry grain material. I think we are not yet prohibited from believing that under certain conditions a smaller amount of water may produce the same result. The actual construction of plant substances out of raw mineral substances is brought about by the chlorophyll of the plant, through energy derived from sunlight. In the arid region the energy derived from the sun at any particular point is much greater in the aggregate than at a point in our eastern more humid, more cloudy, country. I am hoping that we shall see the point demonstrated that while the vegetative growth of your plant may require as much moisture in the arid region as anywhere else, its effectiveness as a starch-making machine is much greater under your brilliant and long-continued sunlight than it is in humid regions. Are you familiar with the fact that in Colorado a heavy crop of apples is usually produced every year by the same trees, while in New York a heavy crop is not expected except in alternate years? Under the conditions which exist in Colorado, an apple tree, in addition to producing a heavy crop of fruit, can go ahead and store up enough food material to enable it to bear heavily in the succeeding year.

I hope you may find it possible to visit Dr. W. A. Cannon at the Desert Laboratory at Tucson, Arizona. Heretofore we have been guessing at the transpiration of desert plants as nearly as we could from their xerophytic structure, but Dr. Cannon has been actually measuring the amount of moisture that types of desert plants transpire under conditions existing at different seasons. In addition to the annuals, which transpire enormously, there are two types of shrubs; those which

store water up for a supply when the dry weather comes, and those which store no water but which struggle through the dry season with an exceedingly attenuated transpiration, deriving their water from day to day and from hour to hour directly from the parched desert soil.

An annual possessing the elasticity in transpiration ability stated by Professor Coville to be desirable would certainly have a distinct xerophytic adaptation, and I may add that in some of the plants from which I made the selection last summer there were a few indications of variation in the direction indicated.

Finally I do not think that the problem of acclimatizing cereals or species of any other kind to arid conditions has been solved. It will require a long time and much patient and careful work to reach the desired goal. But I am fully convinced that although the way may be long it is practicable to traverse it, and that it presents the most satisfactory solution of the problem of arid agriculture in that part of the country which lies east of the Rocky Mountains.

CROP IMPROVEMENT BY UTILIZING WILD SPECIES.

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It has been a favorite of belief of mine for many years that there are yet many wild species of plants which might well repay cultivation and improvement. We must bear in mind the fact that every plant now under cultivation was at one time wild, and that at some place some man first began to give it that care which finally brought it to its present state. For many plants the steps in the modification from the wild to the cultivated state are lost, as is the case with wheat, oats, rye, and barley, of which the wild forms are not now certainly known. But that they were slowly evolved by cultivation, variation (mutation, if you please), and selection cannot be seriously doubted. We have only to consider the history of the development of the many excellent varieties of grapes from the American species of *Vitis*—*Vitis labrusca*, yielding the Concord, Martha, Isabella, Catawba, etc.; *V. aestivalis*, yielding Cynthiana, Cunningham, etc.; *V. vulpina*, from which we have the Clinton, Taylor, Elvira, etc.; *V. rotundifolia*, yielding the Scuppernong, Thomas, and other southern varieties—in order to be assured of the fact that a wild species can be readily changed in a comparatively short time. The same story is told by the varieties of American plums evolved from the wild *Prunus americana* and other allied species. Our gooseberries were likewise derived from a couple of well-known American species (*Ribes oxycanthoides*, and *R. cynosbati*). So too, our raspberries are the more or less modified fruits of the native American species, *Rubus strigosus*, the wild red raspberry and *Rubus occidentalis*, the wild black raspberry.

This list might be considerably lengthened, but it is unnecessary. It is not my purpose to enumerate all the cultivated varieties which have been derived from wild species within so short a time that we