age weight of the individual kernels, which sometimes rose and sometimes fell.

This is not what would perhaps have been expected, and the small number of cases having like ratios makes a general conclusion of rather doubtful value. The facts thus far, however, seem to point to the following as inferences from the experimental data.

1. The shorter the wheat kernel and at the same time the larger its volume, *i. e.*, the more nearly it approaches the sphere in form, the more perfectly will the kernels pack, and the less air-space unoccupied by the grain will be left in the measure.

2. Where the kernels are long, increased average kernel-volume does not insure increased solidity of packing to the measure, but rather the reverse.

3. In general the long types of kernel pack less perfectly than the short types, and should be discarded by breeders in favor of the latter, where pure-bred wheat races are in question.

[Presented by Committee on Breeding Cereal Crops.]

ACCLIMATIZATION IN BREEDING DROUGHT-RESISTANT CEREALS.

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The dominion of climate is invincible. All who come within its range must obey its laws. It grants no pardon. It makes no compromise. Compliance with the conditions imposed is the license to exist, and these conditions determine the limits of activity. Even the achievements of irrigation are the fruits of constant warfare. Every irrigated field is territory wrested from this dominion and maintained by unceasing effort and never failing vigil. The city of Denver preserves its beauty and its charm by constant struggle against the ever encroaching desert, which, encamped and entrenched, maintains sleepless siege against the town. The desolation of Nineveh and the ruin of Babylon are evidence rather of surrender to an adverse climate than of destruction wrought by the hand of man. Thus the testimony of history and the witness of nature demonstrate the truth of Montesquieu's declaration that the most enduring of all empires is the empire of climate.

Acclimatization and naturalization are two radically different methods of introducing new varieties and species. Naturalization is the introduction of plant species from foreign countries where they have become adapted to climatic conditions closely resembling those of the region to which they may be transferred. Were it practicable to find in other lands valuable species so drought-resistant that they would thrive in the arid places of this country, the problem of acclimatization could be laid aside, for its solution elsewhere would render needless its investigation here. But the fact that no such adapted varieties of the common cereals and other valuable crop species can be found makes acclimatization the supreme problem of the arid West.

Wallace defines acclimatization to be "the process of adaptation by which animals and plants are gradually rendered capable of surviving and flourishing in countries remote from their original habitat or under meteorological conditions different from those which they have usually to endure, and which are at first injurious to them." This definition contemplates not only complete acclimatization, but also those slight changes in constitution which enable a plant to endure a moderate climatic difference without the development of new specific characters. Thus one variety may be more drought-resistant than another, and it may have acquired this power by slight variations which would probably disappear upon transfer to a humid environment. Between such varieties and those less drought-resistant members of the same species which have always enjoyed the advantage of abundant moisture, there is not that specific difference which separates the plants of distinctly desert regions from those of distinctly humid regions. Complete acclimatization from humid to desert conditions involves the development of new specific characters.

That degree of acclimatization which involves the development of distinctly desert species is by some naturalists looked upon as chimerical. Prominent among these is Professor de Vries, the eminent Dutch botanist, whose writings form, probably, the most notable recent contribution to the doctrine of evolution. In a little book entitled "Plant Breeding," he expresses the belief that the desert species in the intensely arid region of southern Arizona acquired their drought-resistant qualities by mutations which occurred under humid conditions, that they were expelled from the humid environment, that they reached the desert by migration, and that the desert environment had nothing to do with their evolution.

This theory ignores the fact that adaptation is not found exclusively in the occurrence of a favorable mutation, but in both the occurrence of the mutation and its subsequent perpetuation. One might admit that a drought-resistant mutation could arise under humid conditions, but one could not admit that a mutation of that kind would be an advantage unless there were drought to be resisted. Were a drought-resistant mutation to occur in a region of abundant moisture, it would be a disadvantage, and hence, in all probability, it would disappear before the species could escape by migration. It is only when a mutation is in harmony with the environment that it gives the plant in which it occurs any advantage; and since it is through the advantage given individual plants by this harmony that natural selection operates, the guiding factor in the perpetuation of drought-resistant mutations must be the arid environment to which they conform. Thus the desert, acting as a sieve, determines that drought-resistant plants shall live and that non-drought-resistant plants shall die. From this we are bound to conclude that as a rule desert species have been developed in desert regions.

The assumption which many writers make—among them De Vries—that nutrition can be distinguished from climate in the effect upon plant growth, involves a serious as well as common error. In fact it is impossible to distinguish them, for nutrition and climate can not be separated. In the case of all vegetable organisms, nutrition is the process by which they absorb nutriment and transform it into living tissue. They do this, subject to conditions of heat, light, and moisture. But a prevalent combination of heat, light, and moisture in nature is what we call climate. Hence climate is a factor in nutrition and a measure of the ability of a plant to utilize the nutriment within its reach. A favorable climate stimulates, an unfavorable climate restricts nutrition. The all-important thing to consider is that aridity puts, as it were, hobbles upon nutrition. It is the aim of acclimatization to overcome these restrictions and enable the plant to carry on the work of nutrition in spite of the lack of water.

The way in which aridity restricts nutrition is disclosed by the fact that the service performed by water is almost exclusively mechanical. It holds in solution the nutriment in the soil, conveys it through the roots to the plant tissues, and by keeping the tissues moist facilitates the requisite physiological processes. Ordinarily, a reduction of the supply of water would reduce the nutriment and

restrict physiological activity. In the case of desert plants structural adaptation overcomes this in a measure and enables them to get greater service from the water which is available than they would without this adaptation. The fact that the water which is not retained in the plant is returned to the air by transpiration presents the possibility of a special adaptation. By this act of transpiration a plant may lose a great deal of the moisture taken into its system; and hence a structural adaptation which would check needless transpiration would promote economy in the use of water. The problem of acclimatization is to secure this and other desirable changes in structure.

One should not conclude, however, that in relation to profitable agriculture the possibility of successful acclimatization to arid conditions is confined to the development of direct modifications of the kind in question. For the argument's sake, one might admit that there would be a reduction in the aggregate growth of a plant in consequence of a reduction in the available quantity of water, although observation shows that it is really much less in the case of a plant with drought-resistant adaptations than in one not so adapted. While admitting for the argument's sake the reduction of growth, one should take into consideration the conflict between vegetal growth and reproduction, which has been recognized by botanists since the beginning of vegetable physiology. The circumstances under which this conflict becomes manifest were elaborately presented by Herbert Spencer nearly sixty years ago in one of his most interesting contributions to the theory of evolution. Botanists may differ in regard to the exact nature of the conflict; but that it exists and is closely associated with nutrition is beyond dispute. When nutrition is strong, showing itself in large vegetal development, reproduction is relatively less active; but when a check is placed upon vegetal growth, reproduction sets in. Mr. Patrick Geddes, the British botanist, has given this subject much attention, and he is one of the leading advocates of the proposition that the conflict in question plays a highly important rôle. Arthur, quoted by Professor Bailey in his work on plant breeding, says: "A decrease in nutrition during the period of growth of an organism favors the development of the reproductive parts at the expense of the vegetative parts." Although the case presented is not exactly parallel to that of plants subjected to unbroken poverty of nutrition from the beginning of their lives, the same discrimination

seems to take place when an entire species is compelled to struggle against adverse conditions. In the latter case, natural selection seems to have preserved or perpetuated a tendency to favor the reproductive. In any event, whatever favors the reproductive functions is of advantage to agriculture. Aridity may restrict the aggregate growth, but through a relatively large yield of grain discrimination in favor of reproduction may leave a margin of profit to the farmer. In further support of this view, I may point to the fact within the observation of nearly all wheat growers that a heavy growth of straw is often followed by a disappointing yield of grain, whereas an unpromising development of straw frequently precedes a harvest which yields much more than the appearance of the crop indicated.

In passing, I may remark that if the line of acclimatization is through deterioration, affecting chiefly the vegetal development, but from which the reproductive would not be exempt, the effect upon wheat would probably be seen in a reduction in the size of the grains. If this assumption is correct, small grains might be a mark of acclimatization which the breeder should not ignore.

The methods to be pursued by the breeder now demand consideration; and in this connection I find myself heavily indebted to Professor de Vries, for he has given me a new weapon with which to combat his theory that acclimatization is a dream. One who may be engaged in breeding drought-resistant cereals will have to conduct his experiments only a few years to discover that the desired end is not to be attained by adding one favorable variation upon another. When I began my experiments in 1896 I thought that could be done; but in course of time I discovered that, whereas in one year a plant might show a variation in what might seem to be the right direction, its offspring the next year might just as effectually vary back to the original standard and obliterate all that had been gained. Thus the breeder might find himself swinging like a pendulum between narrow extremes of variation without making any progress. I must confess that, when I was at that stage of my work, I knew nothing about the vicious circle of fluctuating variations concerning which Professor de Vries has so instructively written. There is little hope in the struggle with fluctuating variations. But by his theory of mutations Professor de Vries has pointed out the path of possible escape from the entanglement; and I am now convinced that the acclimatization

of cereals to our arid climate can be accomplished by taking advantage of favorable mutations. But while in theory this simplifies the problem, it greatly increases its practical difficulties. It removes the work to be done from the domain of agricultural to that of botanical experimentation. Solution of the problem calls for a large and fully equipped experiment station, ample funds for carrying on the work, and a force of botanists and other trained men to conduct the experiments. Of the truth of this I am fully convinced by both observation and personal experience. While recognizing that in my own field work I have not solved the problem of acclimatization, I think I have learned something about its nature. My investigations have convinced me that the end to be attained is beyond the reach of individual effort. The work should be done by the Government; and, since the problem is distinctly scientific in character, its solution should be intrusted exclusively to botanists of experience and proved ability. In the hope that in this spirit the work will be done, I look upon it as extremely fortunate that the Department of Agriculture has taken it up. The regret I shall feel in severing my own connection with work of this kind—which I shall have to do in the near future—will be greatly offset if my views respecting the nature and importance of the problem find acceptance. There is reason to fear, however, that a good deal of the labor at the experiment stations now maintained by the Government may be in vain so far as the problem of acclimatization is concerned. Growing numerous small plats of wheat does not hold out much promise of success. Possibly a comparison of yields may show some superiority in one variety over another; but a great deal more than that is needed. The problem is radically different from the one which presented itself to Mr. Hays when he was making his highly successful and instructive experiments to improve the wheats of Minnesota. Acclimatization was not even a factor in his problem. It is the whole problem here. Were we in possession of a fully acclimatized species of wheat, there would probably then be call for experiments like those conducted by Mr. Hays, in order to improve the species and secure a larger yield.

Probably the first thing requisite is full, clear recognition that acclimatization is in reality the problem to be solved, and that its solution calls for distinctly botanical investigations. I fear that at least some of the government experimenters are struggling with the

fluctuating variations of which I have spoken. In their case there is need of recognition that it is only through the discovery of mutations that they can hope to succeed. What is required is the discovery of a new elementary species, drought-resistant in characters distinguishing it from species adapted to a humid climate. It would probably require the trained eye of a botanist to discern these specific characters or differences; but, however this might be, the mutations giving rise to such characters will, in my opinion, have both to occur and to be perpetuated, before acclimatization to an arid environment will be fully accomplished. That mutations of this kind occur from time to time is highly probable; and so my advice to the experimenters is to look for "sports." But let them recognize that a sport showing adaptation to aridity would probably present a very different appearance from that of a sport in a region of abundant moisture. It might, measured by humid region standards, be a most unpromising looking plant—the "singled cat" of the entire field. Probably it would be short in stature, present a dense as distinguished from an open growth, possess a large though short stem, thick coarse leaves and a big development of root. In many respects the last named may be the most important. Neither late-maturing nor early-maturing plants should be rejected. The former might show greater adaptation to aridity; but if the latter should show a special adaptation to the length of the rainy season, they might prove to be very valuable from the standpoint of practical agriculture, although scientifically less interesting than the others.

One obstacle in the path of a breeder compelled to conduct his experiments upon a restricted scale is the comparatively small number of plants available for examination. There is more hope of finding the desired mutations among tens of thousands of plants than in little experimental plats. Should the Government do the work, it could afford to grow five hundred thousand individual wheat plants, if Burbank could grow ten thousand shrubs in the hope of finding a single one with the desired character. The individual plants should be grown sufficiently far apart to give room for careful examination, and they should be numerous enough to give hope of finding the desired mutation. Extensive experimental planting is a prime requisite; for it is not by a kind of training process that acclimatization is to be achieved, but by actually going out and finding the mutations in case they occur.

This leads to a suggestion respecting a way in which success might be achieved. Sheriff, the famous British breeder of fine wheat varieties, devoted his time to looking for sports in the fields, and sometimes years elapsed after finding one before he found another. But from sports discovered by him several superior kinds of wheat arose. Some of the best wheats now grown in the United States are products of similar discoveries. Bearing this in mind, and while still asserting that acclimatization is a botanical and not an agricultural problem, I may consistently suggest that any intelligent and observing man engaged in growing cereals in the arid region by the more or less precarious methods of "dry farming" might stumble upon the desired sport. Hence all dry farmers should be encouraged to look for mutations or sports of that kind. In order that they might search intelligently, it would be well if the Department of Agriculture were to publish a bulletin containing information on the characteristic appearance of drought-resistant plants, which could be distributed among the dry farmers of the arid and semi-arid regions.

One other suggestion to the Department of Agriculture remains to be made. The greatest thing which has ever been done for the study and investigation of arid region plant growth is the establishment of the desert laboratory near Tucson, Arizona. It was established upon the suggestion and under the direction of Mr. Frederick Coville, botanist in the Department of Agriculture, and Mr. Daniel T. MacDougal of New York, both of them botanists of ability and distinction. In the maintenance of that laboratory an example is set which the Department of Agriculture should follow in connection with the endeavor to breed drought-resistant cereals and other valuable crop species. As I already have said, the problem is botanical. It needs botanists for its solution. At one of the arid region experiment stations—and I know of none more suitable than the one at Akron, Colorado—a botanical laboratory should be established. This laboratory should be the center from which all the acclimatization work should radiate. Every supposed "sport" or mutation, whether discovered at the station or in the field of a dry farmer, should be subjected to careful examination; and no doubt much could be done in that way to determine its real value in respect to drought resistance. Mr. Coville did a splendid thing when, in connection with Mr. MacDougal, he secured from the Carnegie Institution the means and later established the desert laboratory near Tucson, Arizona. I should like to see

him follow up that achievement by organizing under the Department of Agriculture a similar laboratory for experiments in acclimatization under the comparatively moderate desert conditions of this part of the country.

Let no one look with indifference upon the possibility here outlined of acclimatizing valuable crop species to arid regions, or underestimate the magnitude of the achievement suggested. The problem itself is as full of interest to the biologist as the possibility of its successful solution is rich with the promise of benefit to mankind. Excluding the untillable mountains and the hopelessly irreclaimable deserts, acclimatization of the food cereals would make arable nearly 300,000 square miles of the now arid part of the United States, increase by thousands of square miles the productive area of Canada, solve some of the pressing problems of agriculture in German Southwest Africa and the South African possessions of Great Britain, extend far into the interior the tillable area of Australia, and by increasing the yield of the fields expel the specter of famine from the grain regions of southeastern Russia. So vast an achievement would rank with the discovery of a new continent in its enlargement of the sources of human subsistence; and well might the hope of success quicken the activities of the most sluggish and awaken ambition in the least daring.

[Presented by the Committee on Breeding Cereals.]