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THE RELATION OF CROP-PLANT BOTANY TO HUMAN WELFARE[1]

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It is with combined trepidation and pleasure that I endeavor to discuss before this gathering the subject of the relation of the botany of crop plants to human welfare. Trepidation because of the difficulty of adequately presenting so important a subject. Pleasure because I believe that a vital relation exists between the botany of crop plants and human welfare and rejoice at the opportunity to emphasize it to others. Let us define what we shall discuss together.

BOTANY

What is botany? The dictionary tells us that it is the science of plant form, structure, function, relationship, and distribution. From this category we evolve several subdivisions of the science; for example.

Phytomorphology, the science of plant form and structure;
Phytophysiology, the science of plant function and growth;
Phyto-ecology, the science of plant response to environment; and
Phytotaxonomy, the science of plant relationships.

Some of these major divisions are themselves subdivided. For instance, taxonomy includes phytography, or plant description; taxonomy proper, or plant classification; and nomenclature, or plant naming, the black sheep of the family. In like manner, plant ecology includes plant physiology and phytogeography, or plant distribution.

In addition to these grand divisions of botany there are some important specialized phases of botanical science, such as phytopathology, or plant diseases; pharmacognosy, or pharmaceutical botany, dealing with medicinal plants; and phytopaleontology, or paleobotany, the science of fossil plants, sometimes called fossil botany. Phytopathology, in turn, includes mycology, or the taxonomy of fungi; physiology, or the function of both host and parasite; and ecology, or environmental response. Finally, there is

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genetics, the science of the origin and expression of characters, the sum total of which makes up the organism as we know it.

Because of the symposium arrangement, it is necessary to restrict the treatment of the theme so as not to trench on the subjects assigned to my colleagues, Dr. Cowles and Dr. Stevens. Omitting their topics, the relation of ecology and of pathology, respectively, to human welfare, there remain the morphology, physiology (aside from environment), and genetics of crop plants, as well as pharmacology or pharmaceutical botany.

At the start we are confronted by the well-known dictum of one class of botanists that, whenever botany relates in any way to human welfare, by that very fact it ceases to be botany. One is reminded of the famous couplet written in similar vein:

My name is Benjamin Jowett,
  Master of Balliol College,
Whatever is known, I know it,
  Whatever I don't, isn't knowledge.

It may be argued that this dictum is but a theory, a state of mind. To those who cherish that delusion it should be necessary only to point out a few striking facts of the botanical past and present.

Development of Botanical Science

Until comparatively recent years practically all botanists studied wild and domesticated plants impartially. This was true of the Greek philosopher-naturalist, Theophrastus, of the third century B.C., the father of modern descriptive botany. It was true of the Greek physician, Dioscorides, and of the Roman, Varro, in the first century B.C., and of the Roman essayist, Pliny, in the first century of the present era. It remained true of botanists in general until toward the middle of the nineteenth century, or some 75 to 100 years ago.

With the revival of learning after the Dark Ages came a renewed expression of interest in things botanical. The first important books of a distinctively botanical character were the so-called herbals, running from those of Ruel in 1537 and Fuchs in 1542 to those of Ray and Morison in 1688 and 1699, respectively. These ponderous folio volumes, written in quaint and not always accurate Latin or in no less quaint English, and illustrated with crude but often startlingly realistic woodcuts, served as repositories of popular and semi-scientific information on plants during the sixteenth and seventeenth centuries. They were based on the writings of the Greek and Roman authors named above, but contained many original observations. Many of the plants treated by the herbalists were in common cultivation, and in that period the crop plants received the same botanical attention as did the feral species. Thus we see that the important early contributions to botanical science were in the field of what, in recent years, unfortunately has been called *applied* or *agricultural* botany.

Throughout the seventeenth century, botanical knowledge was growing rapidly along taxonomic lines. Master minds were laboring to formulate orderly classifications of both wild and domesticated plants. The later and more logical of these attempts are typified in the writings of Tournefort and the elder Jussieu and reached their climax in the eighteenth century in the classic works of Linné, in 1737 and 1753, and in those of the contemporaneous Jussieu the younger. By these and succeeding systematists of the eighteenth century and the first half of the nineteenth century, the leading species and subspecies of important cultivated plants were included and given specific rank as readily as if native and wild.

The writer does not believe that the feral and cultivated species should have received identical treatment, for differences in morphological characters sufficient to separate species of wild plants are sufficient only to separate agronomic or horticultural varieties of crop plants. The point to be emphasized is that the cultivated plants were felt to be worthy the attention of the greatest botanists of all those centuries.

Before the middle of the nineteenth century, a change of attitude had become fully evident. Discussion of crop plants was eliminated from manuals of botany. This change of attitude probably was due to several different reasons. The first, doubtless, was a realization of the difficulties of classifying cultivated crops on the same basis as wild plants. The second was the marvelous improvement in methods of transportation and communication, through the development of railroads and postal facilities. These made possible the botanical exploration of the hinterlands and distributed the resulting collections to botanists everywhere for study, thus diverting attention from domesticated plants. The third and perhaps controlling reason was a growing feeling that useful plants were of a class apart, botanically unclean, and unworthy the best thought of the systematist and physiologist. The result was that, while a few botanists devoted themselves almost exclusively to studies of crop plants, the great majority shunned them entirely. That such a situation should have developed at all was most unfortunate, but that it should have come about just in that period of time was particularly deplorable.

The present era of widespread appreciation and subsidization of the biological sciences was about to be ushered in. The act establishing the system of land-grant colleges was in process of formation. The founding of the state agricultural experiment stations was only 30 or 40 years ahead. The increased appropriations for research in nation and states were to follow soon after. The amazing endowment of great universities was on the horizon. The organization of such great scientific bodies as those in session here was about to become an accomplished fact.

One can almost imagine that the scientific sky must have been aglow with the coming dawn. In spite of this, Botany drew apart and proclaimed herself too sacred to be polluted by the useful. The pursuit of truth for truth's sake is noble, and consecrated thousands have devoted themselves to lives of privation and sacrifice under the inspiration of this ideal. Truth for man's sake is no less noble. If in social science, service to others is the highest form of altruism, how unreasonable the attitude that, in the development of a natural science, no thought for humanity should be allowed to enter.

From our present vantage point of perspective, it seems doubly unfortunate that the botanical fraternity should have lost interest in domesticated plants just at a period when the development of teaching and research institutions would have given them the needed laboratory and field facilities for really effective study. Farm crops as a subject was not and is not taught by botanists. As the writer has pointed out in a previous paper, the original farm-crop specialists entered that field through many doors, including chemistry, the old-time agriculture, and even animal husbandry, as well as botany. On the other hand, when botany did deal with any phase of farm crops she called it "applied botany" or "economic botany," and so erected the wall which gradually shut her off from part of her own domain. From this illogical and unfortunate separation, both botany and agronomy suffer to this day.

Human Welfare

Human welfare may be defined as a satisfactory condition or relation of human society, individually and in the mass. Such welfare must be both material and esthetic. It presumes a coördination of good in the physical, mental, and spiritual realms. Can the botany of crop plants be shown to have any relation to these phases of human welfare? Let us ascertain.

Upon the products of the vegetable kingdom the human race depends for the very essentials of its life. The vital needs of humans are two-fold, food and shelter, and these are important in the order named. The great classes of useful plants which minister to these two needs are cereals, fruits, vegetables, forages, saccharines, and medicinals among the foods, and fibers and forest supplies among the materials providing shelter.

Human Food

Human food is chiefly either animal or vegetable in origin. Primitive man doubtless was both herbivorous and carnivorous. Wild animals furnish as abundant and palatable a food supply as do domesticated animals, but the same is not true regarding feral and cultivated plants. It seems probable, therefore, that primitive man used meat as his staple food, and used vegetable materials to maintain health, to vary his diet, or as a filler. In temperate areas, at least, the necessary supply of roots, fruits, and seeds was obtained only by arduous search and tedious labor in gathering. It could have been abundantly obtainable, also, only during a portion of the year, which would have been less true of animal food supplies. On the other hand, vegetable food materials were more readily preserved for future use than were meats.

The story of the first attempts at cultivation of food crops is lost in the mists of prehistoric time. Seeds dropped about a favorite camping site by members of a nomadic tribe, during preparation or eating, may have produced plants after the family moved on. Later, when they passed that way again, the mature plants with ripened seeds or fruits may have attracted their attention as providing a convenient food supply in a concentrated area. From some such chance observation may have developed the rudiment of the idea of growing the food plant where it was to be used. And no true welfare of human society was possible until man could produce and store food supplies against a time of scarcity and need.

We can even imagine that the quantity and nature of the food supply had its influence on developing mentality. Perhaps there arose, even in those days, the superman who ruled by brain as well as by brawn. And perhaps also there was not wanting an envious Cassius to exclaim: "On what meat doth this our Caesar feed, that he is grown so great?"

The Future Food Supply

The chief problem of the world in the immediate future is the food supply. Across the pages of history one clear record runs. That nation is most secure which has, or can insure, adequate resources of food. Napoleon said that an army travels on its stomach. Not only of the army but of the nation itself is this true. Two thousand years ago the grain ships from Egypt sailed the Mediterranean to imperial Rome. Today the grain ships ply the seven seas to imperial Britain. They go from Australia and Argentina, from India and from Canada, and even from the United States itself. To-morrow they may be steaming toward our shores, carrying a similar cargo.

Ever since American agriculture advanced from the forest clearing to the open prairies and the boundless plains, our country has been a heavy exporter of foodstuffs. Not once have we had to stop and consider from across what seas grain ships should come to us. But now the old order changeth and giveth place to new. With a population increasing rapidly through birth and immigration, and with no large areas of cheap and fertile lands remaining to be brought under cultivation, we come face to face with the problem of our future food supply. Our exports of vegetable food stuffs are steadily declining as more and more is required at home. Our imports of food materials are steadily mounting as the need increases.

This is not written as a pessimistic prophecy but as a sane realization of an imminent problem in order that an adequate solution may be sought. The solution lies in one or more of three directions. First, immediate restriction of immigration and finally the restriction of the birth rate through economic pressure. There are some well recognized but unfortunate biological facts which make this undesirable. Second, an endeavor to import what we do not produce. This puts us at the mercy of other nations in ways of which we have had recent illuminating examples. Third, an undertaking to increase our own production of food to keep pace with increase of population. This last is the only satisfactory decision. How may this result be accomplished?

There are two chief lines of attack on the problem of increasing our food supply. One is to increase the area under cultivation, by reclaiming desert areas through the more extensive and more productive use of irrigation waters, by the reclamation of swamp lands, and by the utilization of the untilled lands in the present tilled area. Some of these are problems in engineering, some in economics, some in soil science, and some in crop physiology. The other possibility is to increase the productivity of the areas already farmed. This requires progress in farm organization, soil science, animal husbandry, crop rotations, plant improvement, plant introduction, and the control of crop pests. Both methods present plant problems which challenge botany to her utmost endeavor.

Botanic Families of Important Crop Plants

We have seen that the crop plants vital to human welfare are those which furnish food, fodder, and medicine for man and his domesticated animals, clothing for him, and shelter for him and for them, and also for his industries. Plants from almost the entire range of the vegetable kingdom are requisitioned to provide material for one or another of these purposes. This realization recalls the promise of Scripture:

> And God said, " Behold, I have given you every herb yielding seed, which is upon the face of all the earth, and every tree which is the fruit of a tree yielding seed, to you it shall be for food " (Genesis 1: 29, Am. Rev.).

The three important classes of food plants for man are the cereals, the vegetables, and the fruits.

Cereals

No other botanic family is of such overwhelming significance to the human race as the grass family, Poaceae or Gramineae, which contains the cereals, corn, wheat, rye, oat, barley, rice, sorghum, and millet, as well as the most important hay, grazing, and silage crops. For those who like statistics, it may be of interest to note that the estimated value of the cereals grown in the United States in 1917 was over $6,800,000,000; in 1918 about the same; and in 1919, nearly $7,300,000,000. Out of sympathy for any botanists so unlucky as to own grain farms, the figures for 1920 are omitted.

A few other plants ordinarily are classed as cereals, though not truly such. Among these is buckwheat, belonging to so distant and unpromising a botanic family as the Polygonaceae, while the closely related family, Chenopodiaceae, contains quinua, a human food extensively used by the primitive Andean tribes. Other plants which are cereal substitutes, in that they furnish starch in concentrated form, such as the potato and similar plants, are discussed under vegetables.

Vegetables

It is somewhat surprising to note how few plant families contain the great majority of the common vegetables of the temperate world. From the Solanaceae come the potato, tomato, and eggplant, not to mention cayenne pepper, the ground cherry, and tobacco, the petunia and the matrimony vine. The Leguminosae furnish beans, peas, lentils, cow peas, soy beans, and peanuts. Another family furnishing a large number of edible roots and plants is the Cruciferae, or mustard family, containing the radish, turnip, and rutabaga, the cabbage and its congeners and derivatives, and the horseradish, cress, and mustard, not to mention such flowers as candytuft, sweet alyssum, wall-flowers, rockets, and gillyflower. From the sunflower family, Compositae in the broad sense, we get lettuce, salsify, chicory, endive, sunflower, and artichoke. The melon family, Cucurbitaceae, contains many large and striking products, as pumpkins, squashes, cucumbers, gourds, gherkins, cantaloupes, casabas, watermelons, and citrons.

In addition to the five large families listed above, are several with fewer economic species. Carrot, celery, parsley, and parsnip represent the Umbelliferae; rhubarb the Polygonaceae, and beets and spinach the Chenopodiaceae. Asparagus and the various onions represent the Liliaceae, while the sweet potato is a morning glory, belonging to the Convolvulaceae, the taro and dasheen belong to the Araceae, and okra belongs to the Malvaceae, with cotton.

Finally, the puffballs, mushrooms, and truffles are fungi, belonging to different families of that large group called Basidiomycetes.

Fruits

The family Rosaceae, used in the inclusive sense, probably furnishes more of the fruits grown in the temperate zone than all other families combined. Among its members are the apple, pear, quince, peach, apricot, plum, cherry, blackberry, raspberry, strawberry, juneberry, and almond, not to mention roses, spireas, and other flowers. Closely related is the family Grossulariaceae, containing the currants and gooseberries.

The citrus family, Rutaceae, ranks next to the Rosaceae in the number and importance of its products, which include the orange, lemon, grapefruit, citron, lime, tangerine, and others. The family Vitaceae probably stands third in rank, with its numerous and varied kinds of grapes, including the so-called currant of commerce.

Other important fruits are the date and coconut, of the Palmaceae, the banana, of the Musaceae, the olive, of the Oleaceae, and the pineapple, belonging to the Bromeliaceae, which includes also the so-called Spanish moss of our southern forests. Such fruits as the blueberries and huckleberries (Vacciniaceae), the persimmons (Ebenaceae), the papaw (Anonaceae), and the mulberry, fig, and breadfruit (Moraceae) should not be forgotten.

Nor should the importance of nuts be overlooked. In nut production, the family Juglandaceae takes first rank, with its walnuts, butternuts, hickory nuts, and pecans. The family next in importance is the Fagaceae, containing the chestnuts, the beechnuts, and the numerous acorns, so important as foods for primitive peoples as well as for animals. Of third rank, probably, is the family Palmaceae, if the widely distributed and important coconut is counted a nut rather than a fruit.

Forages

Among forages the grass family, Poaceae, has by far the largest number of representatives. Chief among the cultivated grasses are timothy, bluegrass, redtop, orchard grass, meadow fescue, bermuda, and sudan grass, as also the cereals. A multitude of native species furnish grazing. Next in importance stand the legumes, Leguminosae, of which alfalfa, clovers, sweet clovers, vetches, cow peas, soy beans, velvet beans, and peanuts are well known and valuable representatives. Beyond these two great forage families stretches a long line of other families some of whose members are grazed, browsed, or ensiled, or otherwise enter into the animal diet.

Saccharines

The principal saccharines are sugar cane and sorgo, both grasses; the sugar beet, like the garden beet, of the Chenopodiaceae; and the sugar maple, belonging to the Aceraceae.

Medicinal and Poisonous Plants

Even to mention the many natural families yielding healing and toxic substances is beyond the scope of the present paper. Certain important examples will occur readily to all. Probably the three most important drug-producing families are the Papaveraceae, or poppy family, yielding opium and its derivatives, so useful in relieving pain, but so terrible in their effects when abused; the Rubiaceae, or madder family, producing the quinine so potent in the control of malarial fevers, as well as coffee; and the Solanaceae, or potato family, producing belladonna, capsicum, stramonium, and tobacco. Other prominent drugs are found in the Araceae, Compositae, Cruciferae, Labiateae, Leguminosae, Ranunculaceae, Rosaceae, and Umbelliferae.

Among the families containing important poisonous plants are the Anacardiaceae (poison ivy, sumach), Apocynaceae (dogbanes), Asclepiadaceae (milkweeds), Compositae (asters, cockleburs, sneezeweeds), Ericaceae (laurel), Leguminosae (lupines, loco weeds, milk vetches, vetches), Liliaceae (cannas, lilies), Loganiaceae (strychnin), Poaceae (grasses), Ranunculaceae (aconite, buttercups, larkspurs), Solanaceae (belladonna, henbane, nightshade, tobacco), Umbelliferae (hemlock), and Urticaceae (nettles). This takes no account of the many poisonous fungi, especially among the fleshy fungi, or mushrooms. The interested reader is referred to the comprehensive manual of poisonous plants by Pammel.

Fibers

The most important fibers are cotton, of the Malvaceae or mallow family, and flax, belonging to the Linaceae. In addition are hemp, of the Cannabinaceae; jute, representing the Tiliaceae; sisal, of the Amaryllidaceae, and abaca, or Manila hemp, belonging to the Musaceae or banana family.

Forest Materials

The two most important families producing forest materials in the temperate zone are Pinaceae, including pine, spruce, hemlock, fir, cypress, and juniper, and the Fagaceae, containing the oaks, beeches, and chestnuts.

Others of importance are Juglandaceae, walnuts and hickories; Aceraceae, maples; Fraxinaceae, ashes; Betulaceae, birches; and Poaceae, including the bamboos. In the tropics many other families furnish materials of high value.

Botany and Crop Improvement

We have seen that the improvement of our present crop plants, or the finding of new ones, is a most promising means of increasing the food supply. The wide taxonomic distribution of the plant families so important to human welfare is an earnest of the complexity of the botanic problem involved. All phases of botany, including taxonomy, morphology, physiology, ecology, genetics, and pathology, must contribute largely if substantial progress is to be made. Ecology and pathology are to have full discussion elsewhere on this program.

Taxonomy

The fundamental contribution of plant classification and description to human welfare has been the presentation of the vegetable kingdom as a fairly orderly series of evolving forms rather than a conglomeration of wonderful but unrelated organisms. The applications of this knowledge of relationships are many, varied, and valuable. Through such knowledge we are able to build up large plant industries with an assurance of success which otherwise would be impossible.

The classification of crop plants, when accomplished with the same precision and thoroughness which have been used in the case of wild species, will be of inestimable value to science and to humanity. The same principles will be applied, the same characters used, and the same results obtained. The *species* of crop plants already are fairly well described and classified. The present need is classification and description of the seemingly innumerable agronomic and horticultural *varieties* of these plants. The duty of taxonomic botany is to make it possible for plant workers everywhere to recognize crop varieties.

A classification of American wheat varieties now in manuscript has determined that the wheats passing under about 800 names actually represent about 200 distinct and recognizable varieties. While the proportion of synonyms in this instance may be no greater than the proportion in any other line of systematic botany, it must be remembered that the results in the case of wheat varieties are measured in bushels and not in bibliographies, in dollars and not in doubts. Such a classification of wheat varieties makes it possible to determine promptly that the so-called Superwheat of a Burbank is identical with the old and well-known Jones Winter Fife of New York and the Inland Empire, and that the only miracle about a "Miracle" wheat is the number of suckers it attracts.

Similar results are coming out of the application of botanic classification to varieties of oats and other cereal crops, and to cow peas, soy beans, cottons, sorghums, lettuce, beans, apples, plums, peaches, and every kind of crop plants. Some years ago the writer saw at one of the largest agricultural experiment stations in the United States a long series of plats of cereal varieties of which less than 50 percent were under the right varietal names. Of what value will be the published results, if the varietal names are wrongly applied?

Ten years ago, in his address as retiring president of the Botanical Society of Washington, Piper recorded his belief that fully 50 percent of the crop varieties published upon in varietal experiments were either untrue to name or unidentifiable. But how shall they become identifiable without adequate description and classification? And how shall they become adequately described and classified without botanists to study them?

Large numbers of important varieties of crop plants have been produced by the selection of pure lines, by the selection of mutations, and by the production and selection of hybrid forms. The intrinsic value of these important strains is great, but there is present the continual danger of their being lost by submersion among the many more or less similar varieties of the crop they represent. Careful botanic descriptions of the recognizable points of difference between them and the forms most closely related, accompanied by adequate illustration, should make it possible for crop growers to recognize these varieties with some degree of certainty.

Throughout the history of agriculture, unscrupulous dealers have substituted inferior material for superior when opportunity has occurred. Increased production of superior strains can be assured only when it is possible to detect substitutions, and this is possible only when all closely related forms are so well described as to be fairly identifiable by an intelligent layman.

Another opportunity of systematic botany in relation to crop plants lies in the finding and introduction of new material. Large portions of the earth still are not well known botanically. The plants of vastly larger areas have not been critically studied with reference to their usefulness in other lands. Some will be of direct and immediate service as food materials. Others will provide hardy or disease-resistant stocks for grafting purposes, while still a third series will possess characters valuable when transmitted through hybridization.

The Problem and the Challenge

To place varietal experimentation on a firm basis of accurately described and easily recognized material; to insure the identity of new and valuable strains; to prevent the faker from profiteering at the expense of crop producers; and to provide new plant materials from the four corners of the earth, is the greatly needed contribution of systematic botany to crop-plant production and so to human welfare.

The work previously done on the classification of varieties of crop plants and the introduction of new material has been the separate product of two different groups of workers, botanists and agronomists. You have heard the saying that no botanist will look at a cultivated plant, and no agronomist at a wild one. Granting the exaggeration, the saying is still too true.

A generation of botanists must be trained to appreciate the fundamental importance of full taxonomic knowledge of crop plants. They must recognize that characters sufficient to separate *species* of wild plants serve only to separate closely related field and garden *varieties* of domesticated plants. In dealing with the latter, they must be willing to forget Latin nomenclature, if need be, as a Latin terminology must be carried to the fifth, sixth, and seventh place in such crops as wheat or corn if one builds on the taxonomic foundations already laid. Likewise, a generation of agronomists must be produced which has had good foundation training in systematic botany, derived in large part from a study of crop plants.

I put the challenge squarely up to the botanical departments of our universities and our land-grant colleges alike to work together to produce such a generation of botanists. Equally squarely are the departments of agronomy in the land-grant colleges challenged to coöperate with the botanical departments in producing such agronomists. This challenge is to the institutions involved.

A similar challenge clearly lies before the present and future personnels engaged in the investigation of plants from both the agronomic and the botanic points of view. The obligation is upon them to coöperate, pooling their valuable resources of accumulated experience and information and expensive equipment in a common cause. Only by such coöperation can satisfactory progress be made in the attack on these problems so vital to the welfare of humanity.

Crop Physiology

At the present time, progress in crop improvement is waiting on a fuller knowledge of crop physiology. To the farmer, as to the agronomist, the value of crop varieties is measured in terms of their performance in pounds or bushels. We know by experimentation that one variety of any given crop yields better under a certain set of conditions than do other varieties of that crop, while under different conditions this same variety may be comparatively unproductive. We know that crops vary greatly in their comparative resistance to disease, to cold, to frost, to heat, to drought, to soil alkali, and to all the other unfavorable factors in the environment. In the same way, some varieties seem unable to stand prosperity. Given what apparently are very favorable conditions, they seem unable to make a proportionate response in production. These things we know, but what we do not yet know is why these things are so. That is the next and most immediate problem in crop improvement.

In the practice of medicine, the detailed study of the functioning of the various members of the human body has been held indispensable to a proper diagnosis of diseased conditions. In the case of even a single one of our most important crop plants, however, no such detailed study has been made. We attempt to acclimatize them in various parts of the world, to make them productive under a wide range of climatic conditions, and to breed them to produce forms with very specialized adaptations, without this fundamental knowledge of their relations, derived from adequate research.

The relative and actual importance of such external factors as light, air temperature, humidity, soil temperature, soil texture, and soil solution in their effect on the growing crop plant at different stages of growth, from germination to maturity, are very imperfectly known quantities today. Without doubt, the increasing determination of the values of these and other factors will have a profound influence on the practices of crop production and ultimately on the quantity and quality of the product.

The recent discovery by Garner and Allard, of the effect on plant growth caused by varying the duration of the daily light period, not only is shaking the foundation of our theories and opens leads toward many unsolved problems, but is highly suggestive of results that will be obtained when other and equally fundamental researches are made in the realm of crop physiology. Some of the lines along which such research should be directed have been mentioned. Next to light, the fundamental factors are temperature, water, and food.

Several unrelated studies of temperature relations have been made, but research to date has touched only the fringe of this problem. Temperature studies are vital to such problems as crop adaptations, including the extension of the areas of fall-sown crops, as against spring-sown; the comparative development of root and shoot and the speed of development of the resulting plant, and the determining of the conditions under which plants may escape or resist the attacks of soil-infecting and other fungi.

The study of water relations is of very high importance. Studies in the water requirements of several important crop plants, as revealed through transpiration measurements, have been conducted in recent years by Briggs and Shantz and by Montgomery and Kiesselbach, but these are only a good beginning compared with the research that is needed.

Investigation of the duty of water in irrigation is much more a problem for the plant physiologist than for the irrigation engineer. The first phase is the determination of the effect of applying water, at different times and in varying quantities, on the comparative and actual development of the roots, vegetation, and fruits of crop plants. The second phase is the possibility of increasing total crop production by making the present supply of irrigation water cover much more than the present number of acres. It is conceivable that reducing the quantity of water by one half might reduce acre production by only two or three tenths and permit irrigation of twice the present acreage. Two acres of irrigated wheat yielding 35 bushels each may be more valuable to humanity and just as profitable to the grower as one acre yielding 50 bushels. It is not unthinkable that one day we shall see governments exercising the right of eminent domain to accomplish such results through reducing existing water rights.

Studies in plant nutrition long have been known to be of fundamental importance. The chief difficulty in such research has been to control experimental conditions and at the same time to approximate natural conditions. Solution cultures permit controlled conditions but give only suggestive results. Fertilizer plats approximate natural environment, but are conducive to confusing interpretations. The gulf between the two may be bridged by continued refinement of method and interpretation.

Studies in the physiology of the development of seeds and fruits in our major food plants, such as the cereals, are of the utmost concern. The period of vegetative growth may be prolonged over several months, but usually the formation and maturing of seeds takes place in the brief period of two to four weeks. Obviously, this is an important and perhaps even critical period in the life of the plant, from the economic standpoint. Physiology can help to show what tillage, or irrigation, or fertilizer practices during or just previous to this period, will influence directly the quantity and quality of the product.

Some preliminary studies in the deposit of protein and starch in developing wheat kernels were made several years ago in the state of Washington by Dr. Thatcher and his associates. Dr. Harlan, of the Office of Cereal Investigations, U. S. Department of Agriculture, is now publishing a series of papers dealing with some phases of the development of the barley kernel. Such studies are but the forerunners of what is required as a foundation for a better knowledge of the behavior of our crop plants at this critical period in their development.

In a present study of soil-infesting rots of the corn plant, coöperative between the Office of Cereal Investigations and the Indiana Agricultural Experiment Station, Funk Brothers Seed Company, and other agencies, some striking physiologic factors have been found to be involved in what was supposed to be purely a pathologic problem. Changes occurring within the plant result in a deposit of harmful metals and consequent severe injury to the plant. Research on the cause of the abnormal metabolism emphasizes how little we know of the functioning of the corn plant in health. And yet here is a crop worth several billions of dollars annually in our own country alone!

During the last half century there has been no lack of attention to the subject of plant physiology. I draw here, however, a clear distinction between plant physiology and crop physiology, because plant physiology has been restricted very largely to studies of wild species. Physiological research in our great state and privately-endowed American universities has not lacked equipment and encouragement. Splendid results have been obtained in such research, but until recently a scanning of the titles of theses submitted in connection with the granting of doctorate degrees warrants the statement that rarely has a candidate undertaken research on a domesticated plant.

The importance of fuller knowledge of crop physiology, in relation to our national welfare, warrants these universities more and more in devoting their magnificent resources of men and equipment to such research. There is no reason why this should not be done in coöperation with plant workers in state experiment stations or in the research bureaus of the U. S. Department of Agriculture. I am sure that the universities would be met more than half way if such coöperation were proposed. There is a large enough field for all, and human need does not warrant the self-imposed exclusion of any agency capable of giving effective assistance in the solution of the problems involved.

Genetics

Some twenty years ago, the rediscovery and interpretation of the remarkable work of Gregor Mendel created a new branch of plant physiology and ushered in a new epoch in plant improvement. As a result, important results are being achieved in two opposite directions. Looking backward, new light is being thrown on the origin of existing plant forms. Looking forward, our knowledge of somatic behavior is being used in the creation of new forms of high intrinsic or potential value.

Genetic studies hold the greatest possibilities for improvement in crop production. The knowledge of the plant sources from which have been developed such tremendously variable and important crop plants as corn or wheat would greatly aid in our understanding of how to proceed in obtaining forms with needed characters. Just as fast as physiologic research can show the nature of such desirable characters as resistance to rust, smut, cold, drought, and the many other pests and unfavorable influences which reduce crop production, genetics will help in combining existing varieties to produce other better adapted ones with the desired characters. At the same time undesirable characters may be eliminated.

Prophets of the New Order

I have been interested to discover what the leaders of botanical thought were emphasizing a quarter-century ago. On consulting the addresses presented about that time by the retiring presidents of the Botanical Society of America and the retiring chairmen of Section G of the American Association, I was particularly interested to find that already they were foreshadowing or openly proclaiming the importance of the economic phases of botany. It was especially interesting to note that three such veterans as Doctors Coulter, Trelease, and Galloway, as well as others, should have had this viewpoint in common. I cite these three especially because the first has devoted his entire career to so-called pure botany, the second has divided his affiliation between the wild and the cultivated plants, while the third has been engaged continuously on various phases of applied botany.

Turning then to very recent pronouncements, I was especially gratified to note the point of view of Dr. Coulter in his address as retiring president of the American Association in December, 1919. In this address, entitled "The Evolution of Botanical Research," he noted three botanical tendencies, as follows:

1. To attack problems fundamental to some important practice,
2. To realize that botanic problems are synthetic, and
3. To recognize that plant structures are not static.

He noted also three important features of future botany, namely:

1. Broader training to be required of botanical workers,
2. More extensive coöperation in research, and
3. Better development of experimental control.

The addresses of Dr. Flexner, three days ago, on "Twenty-five Years of Bacteriology," and of Dr. Pammel, today, on "Some Economic Phases of Botany," are striking records of achievement in applied botany but were given in your hearing and need no discussion here.

Aesthetic Welfare

So far all our discussion has been of the relation of crop-plant botany to material welfare. Its relation to the aesthetic and spiritual welfare of man is less obvious, though perhaps not so much less potent as some may think. At any rate, it is impossible to develop this phase adequately in the limits of the present paper.

When the immortal author of Thanatopsis advised those sick in mind and spirit to "go forth under the open sky and list to nature's teachings," we are sure that the still small voice of useful plants was not excluded from the curative agencies. That scientific worker is indeed defrauded who does not get both mental exhilaration and spiritual uplift from contemplation, in crop plants, of the riotous beauty of floral color, the seductive fragrance of myriad blooms, the marvelous intricacies of structure, and the wonders of adaptation, or from the quietness of far-stretched fields of grain or cotton, and the majesty of towering forest forms, saying, in the latter case, with the dead soldier, Joyce Kilmer, "But only God can make a tree."

In Conclusion

The fundamental botanic requirements in crop production are to know what we now have, to find what exists elsewhere, and to use both in creating something better than either.

To know what we have requires botanic description, classification, and illustration, and a study of plant functioning. To find what exists elsewhere and to predict where it may be useful requires expert knowledge of plant relationships and plant ecology. To create the best requires intimate genetic knowledge, and a visualizing of the plant that is to be in terms of the characters of plants that are. To no more worthy tasks can botanists devote their best endeavors.

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