PLANT PHYSIOLOGY IN SECONDARY SCHOOLS.

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A paper on this subject might properly deal both with what is and what should be taught. Adequately to treat the former topic would demand more time and labor in the collection of data than the speaker has been able to command. A word, however, may here be given to the present status of plant physiology in high schools.

I. WHAT IS.

Here and there a school may be found in which the subject of plant physiology receives considerable attention, but in general it is not well taught. The pupil learns incidentally a good deal about the things which plants do but not much about how or why they do them. If a little laboratory work upon germination is done it is only enough to illustrate the fact that seeds sprout and develop into seedlings. The conditions necessary for germination, the wonderful change of the seedling from almost a saprophytic to a photosynthetic mode of nutrition are taken for granted or ignored. No studies are made of the inter-relations of the endosperm (when present) and the embryo or of the mode of development and rate of growth of the latter. All the phenomena of irritability in plants are dismissed with little more than a mere mention, nutritive processes are hastily summarized and reproduction is regarded as of interest mainly as the function which has called into existence showy floral structures that may be "analyzed." All the way through, the pupil is required to do little more with the fundamental affairs of plant life than to read statements about them and re-tell these in his own language. Least of all is he required to vary the conditions of the plant's existence until he has found out for himself the principal factors in some of its life processes, and the upper and lower limits of temperature, light, moisture and so on under which it can exist.

In other words, the teaching of plant physiology is in many cases very meager and wholly textural and formal. To discuss the causes for this state of affairs would lead one no little way into the history of botany and of science teaching in general dur-

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ing the nineteenth century. It is to be feared that one reason why the dynamics of the plant world receive such scant attention is because it is more trouble to give instruction on that side of botany than on some others. Teachers have said to me "I do not care to do much physiological experimenting; somehow it seems to me too hard to be sure whether the results are correct or not. Then it is discouraging for the class to have experiments fail." It is needless to ask how one would rate the chemistry or physics teacher who made such a remark. Plant chemistry and plant physics are doubtless in part more difficult subjects than either science in its relation to non-living matter. There is, then, all the more reason for doing elementary laboratory work to illustrate the simpler manifestations of energy in the living plant body. It may be granted that a moderate proportion of one's physiological experiments will usually fail—What of it? The most instructive experiment which I ever performed was a failure. A plant of *Ficus elastica* had been under observation for a week or two in a set of measurements of transpiration. Finally it was watered to the point of filling the pot up to the lid which was cemented to its top. Instead of transpiring more abundantly the plant suddenly ceased to lose water through its leaves. Day after day it was re-weighed with the same result, until a yellowing leaf at once gave the clue to the situation. It was dead, and dead plants do not transpire.

2. WHAT OUGHT TO BE.

No one can lay down a course in plant physiology which the high schools should be expected to follow in detail. Botany in some schools is studied for eighteen or twenty weeks and in others for a year and a half. Its place in the curriculum is anywhere from the first to the last year. These facts alone would make it difficult to prescribe the kind and amount of work that should be done. But there is an additional difficulty which arises from the fact that biological studies are so largely conditioned by the environment. The physiologico-ecological problems of the New England coast would many of them mean little to the St. Louisan and still less to the Arizonian. As the political speaker has a different set of promises for every ward, so the judicious botany teacher will shape his courses somewhat with reference to the natural interests of his pupils. It is, however, possible to lay

down some rules as to what it is best worth while to try to teach and how it may be taught.

There can be no doubt of the supreme importance of the physiological side of botany. After all, structures exist only for the sake of the functions which they can perform and we are doing the beginner in botany a radical injury if we let him for a moment forget this. It is easier to keep a prepared slide than a growing plant, easier to demonstrate starch grains than starch manufacture in the cell, but that does not excuse the teacher for dissipating too much time in histological work. To me at least it seems unlikely that we shall often make the mistake of giving high school beginners too full or too accurate an idea of the processes of plant life. Fortunately there are enough good laboratory manuals to tell the teacher what can be done in this way and how to do it. The office of a paper like the present one is mainly to discuss the relative value of the several departments of plant physiology for secondary school instruction and to set down in orderly fashion some of the principal categories under which the subject should be considered.

In a general way it is evident that we should lay most stress on the processes which are most important in the life of the plant. But some of these such as mitotic division of the nucleus, are far too difficult to be followed in detail by ordinary high school pupils. It therefore becomes necessary to modify our statements and to say that one should teach those topics in plant physiology which are of great intrinsic importance and which are workable under secondary school conditions. Clearly, following this course will throw a good deal of emphasis on the activities of the entire plant body or its organs as wholes rather on intracellular work. It will also lead us as far into physiological ecology as the principals and superintendents will let us go. The fact that public school classes cannot be kept many hours away from the school building precludes a great deal of field work. Still a good many subjects can be dealt with by means of reports on field work done by designated members of the class, supplemented by laboratory studies made by the entire division.

Summing up the subjects in plant physiology which can profitably be handled by a good secondary school class in a well equipped laboratory, they may be grouped somewhat as follows:

1. Growth and differentiation of the plant body, from the seed to the mature plant with seed of its own. Studies of the external developmental changes undergone by the plant.

2. The vegetative work of the plant. Studies of the nutritive activities of plant tissues.

3. Reproduction. Studies particularly of sexual reproduction all the way from the simplest zygospore formation to the fertilization and development of the ovule in seed plants.

4. Responses of the plant to the demands of its environment. Studies of all such manifestations of irritability as help the plant to adjust itself to its conditions of life. Also the investigation of some such plant structures as seem to have been evolved as means of protection against hostile conditions. This may seem much more ecological than physiological study, but after all there is little except the floristic and the geographical side of ecology which is not essentially a part of physiology.

It would be a wearisome and time-consuming labor to enumerate all the studies and experiments which might be undertaken in carrying out the course of plant physiology just outlined. But it may be worth while to suggest a few of the most important topics to be dealt with under each of the four heads above given.

Under the first come studies of germinating seeds, investigating the conditions under which germination is possible and ascertaining the optimum amount of such factors as air, moisture, and temperature. The rate of growth of the organs of the young seedling may be measured and their relative extension in various species compared, with discussion of the differences observed. The development of leaf buds may be followed through one season and the history of branches traced backward through many seasons. The origin and extension of conducting and strengthening tissues in root, stem and leaf may be partially followed. Evolution of flower buds into flowers may at least be outlined.

Under the second head the amount that can be done must depend a good deal on whether or no the class has any knowledge of chemistry. If it has, the whole subject of nutrition may be taken up in an elementary way. This should include studies of the sources of the raw materials of the plant body, of the osmotic activity of cells, of the transference of liquids throughout the plant body, respiration, photosynthesis, and the storage and subsequent utilization of reserve materials.

The treatment of the third general subject, reproduction, need not be discussed in detail. It is perhaps sufficient to say that a considerable series of studies of its simpler forms will greatly

clear up the student's comprehension of what the process really signifies. It is perfectly possible to deal with some of the steps in the evolution of reproductive processes even in courses where not much time is spent upon the study of spore plants. This can only be done by concentrating the attention upon the gametes minimizing the treatment of other stages in the life histories.

Under the fourth head, responses to environment, satisfactory work must, as already suggested, much of it be done in the field. This, however, would in any case need to be largely supplemented by laboratory studies, and some topics can be handled entirely from the laboratory side. A very few of the subjects that may be investigated are the struggle for existence among buds and branches, the influence of varying degrees of illumination on foliage, the hibernacula or the summer resting condition of perennial herbs. Much that is interesting may be learned about the structural and functional variation of xerophytes under widely differing conditions as regards water supply. Heliotropism of stems and leaves and the changes of leaves and flowers from the diurnal to the nocturnal condition and back may be examined in a quantitative way. For the pupils who can do out-of-door work, even with a single flower bed, a large amount of spring study can profitably be devoted to the actual working of floral arrangements for insect pollination.

But it is needless to multiply examples of the many points of view from which the plant may be approached and interrogated as to its life processes. One important suggestion is that every member of the class need not be, I had almost said must not be—given just the same observations to make and the same problems to solve. Much more can be done by allowing some liberty of election, at any rate in field work.

So far I have said next to nothing about plant physiology as exemplified by the lower forms. Of course the activities of the higher plants are so much more varied than those of the thallophytes that the former afford far more material for physiological observations. It would be difficult to put in figures the comparative responsiveness of a *Pleurococcus* cell and a sensitive plant, as they appear to the beginner in plant physiology. And yet the very simplicity of the life of the less differentiated spore plants makes them admirable material for the study of many life processes. Such subjects as osmosis and plasmolysis are nowhere better illustrated than by cells of *Spirogyra*. Ordinary cell di-

vision and multiplication by budding are well shown by *Spirogyra* and *Saccharomyces* respectively.

Various movements such as ciliary action, phototaxis, amoeboid movements and protoplasmic streaming are best shown by certain spores or spore plants. The series of steps in sexual reproduction which culminates in the process as found in seed plants can be traced from its simplest form, as exemplified in *Spirogyra* and the desmids to its penultimate stage in *Selaginella*.

Among the higher spore plants there can be found many remarkable degrees of adaptation to extreme conditions as regards water supply. Most of the so-called water ferns, for example, are true aquatics. The majority of our common ferns are denizens of moist woods. But some ferns, like various species of *Notholaena*, *Cryptogramma*, *Polystichum*, *Cheilanthes*, and *Pellaea*, are extreme xerophytes. A few of our ferns are tolerant of full sunlight, many prefer moderate shade and some, such as *Cystopteris fragilis* and *Adiantum Capillus-Veneris*, flourish in the mouths of caverns and rock shelters, where the average illumination is probably much less than five per cent of that of unshaded places.

Dismissing in this rather hasty way the outline of physiological processes to be studied and of material to be employed, there remains for discussion the manner in which the work is to be handled. Here the speaker must confess himself to be at a decided disadvantage. For in nearly twenty-five years of botany teaching it has been his misfortune always to have had to do without any laboratory facilities worthy of the name. There may be other such unfortunates in the audience, teachers who have also been victims of home made apparatus and of the school desk masquerading as a laboratory table. Experiences of this sort lead one to emphasize as indispensable for satisfactory results the use of an adequate, well-stocked laboratory. For physiological work most important requisites are well regulated temperature, sunshine and, (if possible) a small greenhouse or its equivalent. Even a large, heated bay window with waterproof floor and an atmosphere kept thoroughly moist by large exposed surfaces of wet sand or other porous material will answer. It must be kept in mind that in winter the air of a room heated and ventilated in the ordinary manner is practically desert air, capital for decided xerophytes but death to many of the plants best worth studying.

In the way of expensive apparatus the secondary school need

not provide much except compound microscopes, a clinostat and some moderately sensitive balances. Fortunately the temperature relations of plants can be quantitatively studied with a chemical thermometer, the light relations with a watch and bits of sensitized paper and the transpiration rate with a fairly good balance. These are only typical examples of the many cases in which actual research of scientific value can be accomplished in the field of plant physiology with very simple appliances. The golden mean in regard to apparatus is to give the pupil enough to secure good results but not enough to spare him painstaking or to obscure his view of the process under investigation behind too complex appliances for observing it. Probably most high school pupils would not observe as carefully or as long remember their results concerning the growth of internodes, measured by a self-recording auxanometer as they would such values as could be secured by the use of a pair of dividers and a millimeter scale.

It is still to some extent a mooted question whether the pupil should be told beforehand what values he ought in any given experiment to obtain. Some teachers (otherwise sane) insist that it is necessary first to teach the correct results in order that the pupil may not obtain for himself incorrect ones and then remember them forever. To me this fear has always seemed baseless and many experiences have led me to apprehend much more danger from setting the student to work under the influence of preconceived ideas. Many years ago I had charge of the physics instruction in an important fitting school. The text-book in use contained a calculation of the specific heat of lead in which a wrong value was given for this constant. When the class reported their determinations of this specific heat, a large number of the results closely approached the wrong value given in the text-book. Now this sort of thing does not necessarily imply a deliberate falsifying of notes. It often means nothing more than that the student has re-read his record and honestly felt that there must have been some mistake in setting down data. The next step is to revise these so as to eliminate the probable error. Any of us who have had enough laboratory training to have acquired the habit of accepting facts on experimental evidence, without the evidence of some other person to identify them for us as facts, find it hard to realize the state of mind of the pupil. His education may have been largely linguistic and (as has often been said) he knows of no way to find out the truth except to

look first through the rules and then the exceptions of his grammar or its equivalent. Now though the experience of most of us would doubtless lead us to set laboratory work first and textbook statements, with discussion of results afterward, this plan does not preclude assistance from the teacher as the laboratory observations are in progress. It is an indefensible waste of time and of interest in the subject to let a student spend his laboratory period in futile attempts to get things going. If he is using the compound microscope for the first time and sketching mainly air bubbles, if he is trying to plasmolyze a dead *Spirogyra* cell, he should be set right at once. The frequent presence of the teacher at the pupil's elbow, in the laboratory, saves much waste of energy, minimizes the opportunities for copying the results of others, and secures thoroughness. The last point is most essential, for there are few temptations which more frequently beset the beginner in any kind of laboratory study than the tendency to be too easily satisfied with first results. In discussing with pupils the results of observations and experiments on yeast cultures made at home, I have found that immersing a test tube full of the fermenting mixture in boiling water for fifteen minutes was usually reported to have caused increased production of gas. This result was given by the pupils in spite of the written direction to allow the mixture after heating to remain for an hour or more in a warm place. Of course the tube was examined while it was in the boiling water or upon withdrawal from it and not looked at afterward.

A most important practical question that at once confronts the young teacher who is arranging the schedule for his year's work in botany is how to divide the time between laboratory and classroom. Doubtless the former should have a good deal more than half of the time, but just how much more is a question to be solved for each case independently. To me it seems that the young and enthusiastic teacher is rather likely to overdo the laboratory side of the instruction. A good deal of experience in summer school teaching has convinced me that there are few cases of congestion more fatal than those of people who have accumulated a large mass of notes on experiments which they have performed in more or less complete ignorance of what they were doing and why they were doing it. They are left in much the same unhappy condition as that of Mr. Alcott when at the close of one of his famous conversations on Emerson and the

Concord transcendentalists he was asked by an alert Chicago board of trade man, "But, Mr. Alcott, what is it all for?" Perhaps as good a rule as any is to discuss laboratory results in the class room as long as they naturally lend themselves to furnish material for interesting recitation. Then new queries may be raised and the class be put in an expectant attitude so that the opportunity to solve the new problems in the laboratory will be cordially welcomed.

In conclusion it may be well to say a word as to the amount of detail and the thoroughness with which the subject of plant physiology can be studied by high school classes. Authors differ most radically in the thoroughness with which they handle the fundamental topics of this subject. In some high school text-books it is relegated to what is virtually an appendix, while in a few it constitutes the leading part of the general treatment of botany. Taking specific examples, one moderately well known book gives no more detailed explanation of the chemistry of photosynthesis than this: "Carbon dioxide taken from the atmosphere is somehow used up in this operation (manufacturing plant food), and the oxygen which is not needed by the plant is given back to be consumed by animals." Another book, rather difficult for high school use, gives about two and one-half pages to the explanation, makes free use of the terms chloroplast and photosynthesis, gives the chemical composition of carbon dioxide and of water and states that photosynthetic work is due to solar energy. A still more striking disparity of treatment can be found in the case of the subject of fertilization in angiosperms. One author gives the topic (not including cross-fertilization) eleven lines without a single cut, while another gives it nine pages with twelve elaborate cuts. The latter author also employs the most modern terminology, calling the pollen grain a *microspore*, the two cells within it resulting from nuclear division a *male gametophyte* the embryo sac a *megaspore*, and the egg apparatus with accessory nuclei a *female gametophyte*. Between such extremes of treatment as those just given there is a wide range of choice for the teacher.

The rigorousness with which the subject of plant physiology should be handled in the high school ought to be just that which will bring in the largest returns of knowledge of the subject and training of the student's powers without overworking him. Any approach to what ordinarily passes for the nature study method of presentation is out of the question. Too often such treatment

in the lower grades has left the pupil saturated with the idea that he has "had" botany, physiology, zoology or what not and therefore quite unwilling to bend his energies toward learning more of it. On the other hand it would be most unfortunate if the subject were attacked in such fashion as to call for more reasoning power than the high school boy or girl has developed and thus become thoroughly repellent by reason of its difficultness. Apparently the very exacting preparation in physics demanded by some college entrance requirements has, with great numbers of students, resulted in leaving memories of the course as one long nightmare. Our plant physiology should be sufficiently exacting to call for thoroughly careful laboratory work and subsequent reading; it should stand for much in the way of developing a scientific habit of mind, but it need not—must not serve to make the plant world odious. Rather should it add greatly to the student's interest and pleasure in the society of his plant neighbors. If we can arouse in our student ever so little of that enthusiasm about the life and behavior of plants which animated such diverse investigators as Sprangel, Delpino and Müller, Humboldt, Grisebach and Schimper, Knight, Darwin, and Sachs, we may feel that our teaching has not been in vain.

FIELD TRIPS IN BOTANY.

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It is astonishing, at the present state of botanical teaching, to hear an occasional botanist still objecting to the field trip for High School students. Time was when a field trip meant an excursion for plants later to be pressed for the herbarium but at that time the study of botany was largely of the kind described as "pulling flowers to pieces in a laboratory." If teachers simply object to the old-fashioned botanical field trip, certainly we may all object with them, but this need not prevent our changing the object of our field trips just as we have changed the subject matter of the course itself.

The fact is, botany is the one science in which the field trip is most necessary, or at any rate most useful. To be sure the pupil can get a pretty thorough idea of form, function, and structure from pickled specimens without leaving the laboratory, but unless field trips are taken he entirely misses that most val-