THE EDUCATION OF AN AGROBIOLOGIST

An address to the directing heads of agricultural instruction in the United States,

by

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The following remarks have been inspired by letters addressed to me by prospective students inquiring where they might obtain instruction in agrobiology; they are here offered as a suggestion that departments of plant biology in agricultural colleges and universities reëxamine the subject matter of their instruction to see how far they are prepared to satisfy such inquirers.

An agrobiologist is an academic or a practical plant biologist - botanist, plant physiologist, ecologist, agronomist or dirt farmer - who by experience and observation has attained a comprehensive perception of a condition that pervades the entire vegetable kingdom: The interaction between any plant species and any factor of its growth is a simple irreversible mass action of the first order, which in all cases reaches a state of equilibrium or end-result that is quantitatively as definite, as measureable and as controllable as any chemical mass action of the same order that is effected in chemical laboratories or factories. A plant biologist who has attained this perception is an agrobiologist, whether or not he describes himself as such.

A practician of plant science who has acquired a full understanding of this condition will have a working knowledge of the quantitative limits of agrobiologic equilibria, and will be in a position to make a rational adjustment of the factors of these equilibria so as to obtain a desired quantitive end-result within these limits. Further, he will have obtained a perception of one of the major lines along which the breeding and selecting of plants may proceed toward an expansion of the present genetic limits on the potential yielding abilities of plant species.

Agrobiology is not Agronomy

However, it is distinctly to be understood that agrobiology is not agronomy nor plant physiology, as these subjects are currently understood.

Agronomy is defined by the lexicographers as the management of land; rural economy; agriculture. It is a utilitarian art. Agronomics, which the dictionaries tell us is the business of managing farms, is bounded on all sides by economics. The individual agronomist or farmer is interested in plants and the factors of their growth chiefly because he must depend on them for his living, and he dares not stray beyond plainly visible dollar marks. The chief business of the agronomy departments of the agricultural colleges has been and still mostly is to impart such instruction and to make such studies as are thought likely to enable farmers to make profits. It is called agricultural science, but it is really shot through and through with a plodding empiricism.

Agrobiology, on the other hand, approaches the study of plants and the factors of their growth as though there were no such things as economics or dollars and cents. What the agrobiologists seek to establish, and what they have already gone far in establishing, are the definite and immutable relationships between quantity of plant growth and quantity of growth factor in the fields, regardless of whether some of these relationships, or any of them, have pecuniary implications. An agrobiologist is essentially a seeker of ultimate truth, a student of the fundamental principles of plant yields as a pure science completely dissociated from the fluctuations of economics. But once he has come to a clear perception of these fundamentals he may scientifically solve practical problems of agronomics that are now mostly beyond the ability of the average empirically trained agronomist.

There are three foundation principles (which have numerous offshoots and corollaries) that lie at the base of sound agrobiologic education. Agronomic teaching or practice that is not fully, directly and consciously grounded at all points on these principles is empiricism and not science.

First Principle: Reproducibility of plant yields.

A student of quantitative plant life is on the way of becoming an agrobiologist when he really learns, by experiment and observation, that a cycle of plant growth is quantitatively reproducible, in the following sense:

When a sufficiently large number of seeds or cuttings of any genetically stable variety of plant is cultivated in an environment that has been standardized in respect of unit space, temperature, light, moisture, soil reaction and supply of plant nutrients, the end-result is a certain definite yield of vegetable dry substance. If the operation is repeated in an exact replica of the original environment, exactly the same weight of dry vegetable substance is obtained as before. within a limit of experimental error which competent experimenters can (and do) keep well within one per cent. From such observations the perception is gained that any definitely established condition invariably results in the same definite amount of plant growth. By "definitely established condition" is meant a set of circumstances that is replicated without any change in the kind of material planted or in the character of the environment.

My observations of non-agrobiologists indicates that they have dim conceptions of this fundamental principle, and do not fully realize its universality in plant life. On the contrary, there is a more or less prevalent notion that the plant, by virtue of a mystical power of life that resides in it, is to a degree independent of its environment and is in a measure able to dominate outer circumstances instead of being completely dominated by them. Any trace of such mysticism is fatal to the agrobiologic viewpoint. By genetic processes some kinds of plants may be endowed with adaptability to circumstances that are inimical to other kinds of plants not so adapted, but this means only a substitution of one set of limiting circumstances for another. Whatever may be the inner quality of any vegetable organism yet known to man, its yield in any environment is invariably a definite function of the character of that environment.

To be sure, the mystics among plant biologists find some color of reason for their feeling that plants are to a degree independent of their environment, in the fact that the same plant species may produce identical amounts of vegetable substance in environments of widely different compositions. Does not this bespeak for the plants a certain independence of circumstances? It does not, and the reason it does not is to be found in the subjection of all plants to the mass action law, by which it is ascertained that the reaching of identical end-states in different environments is wholly governed by the quantitative proportions of the growth factors present in the environment. To anticipate what will be said further on, the goal of agrobiologic education is to put the student in a position where he can evaluate and control the mass-action systems which he will encounter at every step in his career as a practical plant culturist.

In this preliminary stage of an agrobiologist's approach to an understanding of the mass action law in quantitative plant biology he will have been brought to a realization of two fundamental conditions: the absolute reproducibility of the results of plant growth in any fully controlled environment and, correlatively, the presence of an inescapable limit on the quantity of plant growth in any environment. The clearness with which these fundamental conditions are perceived will depend on the extent of the factual observations which the student is required or encouraged to make. These observations may well be thorough, and may be based on direct experiments and a critical examination of all available published data. Examination of published experimental work may well be critical, because much of it is obviously vitiated by omission to assure control of all essential conditions.

It is desirable to extend this phase of the instruction to include as many different environments and as many different kinds of plants as possible, with the purpose of fixing the concept that whatever may be the character of the constant environment or whatever the kind of plant, the yield of that plant in that environment is inevitably constant and characteristic of both.

Second Principle: Plant species have characteristic growth powers

While the student will be absorbing the fundamental fact that quantity of plant growth is accurately reproducible, and is characteristic both of the plant species and of the environment in which it is grown, he will hardly avoid becoming aware of several other fundamental conditions. One is that when two or more genetically stable plant species are normally cultured in the same constant environment, they may give the same or different yields. If the yields are quantitatively different, then the quantitative difference between them will persist in every replication of the system. This shows that under the urge of the same collection of external stimuli one plant species may yield more than, or less than, another. In other words, under identical outer circumstances, one plant species may be found displaying a greater quantity of vital energy than another which grows beside it.

To some readers this may seem to overemphasize a commonly admitted fact. It is very well known that different varieties of wheat, for instance, differ in yielding ability when grown on the same soil. But it has remained for agrobiology to introduce the concept of quantity of plant life, and to give a measure thereof in terms of a quantitatively dimensioned environment. The student must come to recognize quantity of

life as a specific property of every plant species in order that he may become able to measure this life on a scale that is not merely comparative, but absolute.

It should be understood that all the basic facts and principles of agrobiology have been qualitatively known for decades and some for thousands of years. The function of agrobiology is to place this qualitative knowledge on a quantitative basis. Without this transition it will be impossible to have any real science of plant culture.

Third Principle: Yields increase by diminishing increments

Another general condition which the student of agrobiology must approach on the quantitative side is that the yield of any plant species varies with the concentration or intensity of any given growth factor in an otherwise constant environment. He will note that as the concentration of such a factor is increased, the yield of vegetable substance is also increased; and that in the reverse progress of decreasing the concentration or intensity of the factor the yield is diminished; i. e., the quantity of vital energy displayed by the plants is in direct dependence on the available quantity of their growth factors. Hence quantity of yield and quantity of growth factor are inseparably and positively correlated. It is a main function of agrobiology to ascertain the numerical values appertaining to each member of this correlated pair, i. e., to express consequent yields in terms of antecedent circumstances.

When this relation is attentively observed it is found that the relation is not linear; successive equal increments in the concentration of the growth factor do not evoke equal increments of vital energy in the plants. That is, the yields of the plants increase by diminishing increments until a point is reached where further accessions of growth factor produce no further increase of yield.

Here again it may appear as though commonly known facts were being overemphasized. Few practical agriculturists are without some notions of the law of diminishing increments of yield as applied to the use of growth factors in plant culture. But it is at this point that the cleavage between the agrobiologist and the non-agrobiologist comes into the open. The non-agrobiologist's notions of the law of diminishing increments, being merely qualitative, are vague, mostly without form and largely void because they are not quantitative. That is, the non-agrobiologist has little if any notion of absolute units either as regards quantity of growth factor or quantity of plant life, and *a fortiori* has little or no notion of a definite numerical relation between the two. Still less is he able to deal with plant growth as it occurs in systems that are under complete subjection to the mass action law, which is always the case with every known kind of plant *vis a vis* every known growth factor. Without ability to define the fundamental units and to correlate them, the law of diminishing increments becomes a stumbling block and the quantitative aspects of plant life are not reducible to a real science. On the other hand, the agrobiologist learns to clothe the law of diminishing increments in mathematical verities and thus to convert plant culture, which otherwise is a morass of empiricism, into solid ground on which a real quantitative science of plant life may be and is being erected.

The three basic principles of agrobiology summarized

The object to be attained in this first phase of the agrobiologist's education is to assure that he shall well comprehend the three basic principles of agrobiologic science:

(1) - The absolute quantitative reproducibility of plant growth in a constant environment.

(2) - The absolute differentiation of plant species by their quantities of life.

(3) - The universality of the law of diminishing increments of yield.

These principles are absolute in their application to every known kind of plant, in any known part of the earth, and in every known circumstance in which plants are found to grow. Every aspect of quantitative plant biology is affected and determined by their joint - and inseparable - influences. They are to the science of the quantity of plant life what the Euclidean axioms are to geometry - the ultimate authority for all computations involving quantity of plant growth.

Proceeding upon the foundation thus laid, the next phase is the practical one of evaluating the absolute units of growth factors on the one hand and the absolute units of quantity of plant life on the other, and of establishing the numerical correlations between these two categories of fundamental units. What this second phase chiefly amounts to is a process of clothing the law of diminishing increments of yield in mathematical verities.

Evaluating the units of growth factors.

The process of defining the absolute units of the factors of plant growth involves nothing more recondite or difficult than collating the quantitative results of plant culture, wherein the concentrations of growth factors have been varied under strict control in environments that have otherwise been maintained constant. This field is explored step by step; at first a single plant species and a single factor of plant growth are carried through the gamut of their quantitative relations. The end-result of such a specific study is a quantitative evaluation of the response of that plant species to graded amounts of that growth factor. The same process is continued ad libitum with other pairs, and is eventually extended to include the presence of two and more growth factors that are simultaneously varied in the same or in opposite senses.

The science of agrobiology as it exists today is built upon the results of detailed studies of this character by many investigators in many countries with practically all plant species of commercial importance, perennial as well as annual, arboreal as well as herbal.

What before was only qualitatively known has become quantitatively defined. The first agrobiologists had before them the universally recognized fact that all plant growth depends on a limited number of physical and chemical agents, that each of these is indispensible and cannot be replaced by any other, and that the growth-promoting values of these agents are in some way related to their active masses or concentrations in the environment.

The transformation of this qualitative perception into quantitative knowledge has required only painstaking experimentation in field and laboratory. The volume of this quantitative experimentation is now such that all the principal factors of plant growth, especially the principal chemical factors of soil fertility, have been tagged with their characteristic agrobiologic energy-indexes, or Baule units, through which their agrobiologic effects may be traced in any environment.

The general result of this quantitative tagging of growth factors is that the yield-producing value of any environment becomes subject to mathematical definition by a general equation of the form

$$y = (f)E$$

in which $\underline{y}$ is the yield that is producible by an environment having the specific energy-index $\underline{E}$, which in turn is the product of the energy values of all the individual growth factors, positive as well as negative, that are present in that environment.

The agrobiologic mass-action formula

When the student of agrobiology has arrived at the foregoing generalization of the relation between the yield of a plant species and the character of its environment the next step is to reach a definition of the limit values of $\underline{y}$ and $\underline{E}$. The existence of ultimate limits on both $\underline{y}$ and $\underline{E}$ is predicted in the law of diminishing increments itself: no variety of plant cultivated in any environment, no matter how well supplied with the factors of plant growth, has ever been found to produce an unlimited quantity of vegetable substance on a unit area of land in one cycle of growth; every attempt to force a larger yield by intensifying mass actions in the environment has invariably been met by diminishing increases. Thus it is found that the power of plants to grow and yield, and the power of growth factors to promote plant yield, are mutually terminate: the yield evoking power of an environment comes to a finish when it contains just enough of each of the essential factors of plant growth to produce all the yield of which the species is capable.

Since, in the limit, the growth-promoting values of growth factors and the quantities of life of plant species are mutually terminate, the quantity of life resident in any particular plant species can be measured by providing for it an environment in which a full complement of all necessary growth factors - *i. e.*, ten Baule units of each - has been assembled.

A number of formulas have been proposed for expressing the numerical relation of plant yields to growth factors. Among these, the only formula which employs absolute units of growth factors and absolute units of quantity of plant life is the Mitscherlich yield equation as extended by Willcox. This formula is the one which has received by far the greatest amount of support from experiment and observation in the most different parts of the earth and with the most different kinds of plants, and is used by agrobiologists in the manner and form given below:

When the ultimate quantity of life, $\underline{Q}$, residing in any stable plant genotype has been ascertained by the known experimental methods, and when the characteristic agrobiologic energy-indexes

$$k_1\ k_2,\ k_3\ .\ .\ .\ .\ k_n$$

have been determined for each of the essential factors of plant growth

$$x_1,\ x_2,\ x_3\ .\ .\ .\ .\ x_n,$$

also by known experimental methods, the final equilibrium or end-state of any operation in plant culture is quantitatively defined by the general agrobiologic working equation

$$y = Q(1 - 10^{-x_1k_1})(1 - 10^{-x_2k_2})(\ .\ .\ .)(1 - 10^{-x_nk_n}),$$

with which it is possible to evaluate, quantitatively, the mass actions between any stable plant genotype and any single factor of plant growth or any combination of known growth factors.

Without the training, knowledge and experience required for gaining a working command of mass actions in plant culture the non-agrobiologist, whether he is head professor in a major university or the responsible manager of a plantation, is restricted to the plane of empiricism, unable to correlate with sureness the vital and material forces with which he is working.

On the other hand, having ascertained beforehand (by the use of known methods) the maximum quantity of life, Q, resident in any plant species, and knowing the agrobiologic energy-values of the common factors of plant growth and the quantities of them available at the moment, the agrobiologist can foresee the end from the beginning, just as surely as the chemist can foresee the end-result of the interaction between chemicals whose valencies and reaction characteristics have previously been established by the known methods of chemical research.

The chemist and the agrobiologist, trained in what for all intents and purposes are exact sciences, are in a position to guide their operations by the same general mass action law, in so far as they know the dimensions and have control of the factors with which they are working. Unknown factors, or factors which for one reason or another (economic reasons, for instance) are not subject to their control leave the one as helpless as the other. What the industrial chemist does in such cases is to use the established principles of pure chemistry to disclose the nature of the unknown system, and thus to discover how to approximate therein the standard result of an ideal chemical reaction.

In the new agriculture the scientifically trained agrobiologist will have the similar function of quantitatively diagnosing unknown or refractory systems in the open fields and of bringing them as closely as possible into harmony with established agrobiologic norms. His task will be complex and difficult, which is all the more reason why the leaders of agricultural practice should be well grounded in the basic concepts of agrobiology and in the laws of plant growth and yield that flow naturally and surely from them. No teacher of agronomy or of any other division of applied plant biology will be giving his students anything of genuinely scientific value unless he ties his instruction at every step to the three universal principles of agrobiology, and through these principles approaches individual systems with the measuring tape of the agrobiologic mass action law.

Conclusion

Agrobiology is to plant culture what stoichiometry and chemical dynamics are to chemistry. It is unthinkable that industrial chemistry would be satisfied to leave its laboratories, research institutions or works under the direction of chemists trained in schools where these fundamentals are hardly known by name or content. Yet (or so this writer believes) the parallel situation is still too much the case with agriculture.