

Bulletin No. 147

June, 1934



**University of Arizona**  
College of Agriculture  
Agricultural Experiment Station

**Fundamental Concepts in Plant  
Research**

By

**J. F. BREAZEALE**

PUBLISHED BY  
**University of Arizona**  
TUCSON, ARIZONA

# ORGANIZATION

## BOARD OF REGENTS

HIS EXCELLENCY, B. B. MOEUR, M.D., Governor (Ex-officio).....	Phoenix
HON. HERMAN E. HENDRIX, Ph.D., State Supt. of Public Instruction (Ex-officio).....	Phoenix
Appointed Members	
HON. ROBERT E. TALLY, B.S., M.E., President.....	Jerome
HON. SAMUEL L. PATTEE.....	Tucson
HON. FRANKLIN J. CRIDER, M.S., Vice-President.....	Superior
HON. THEODORA MARSH.....	Nogales
HON. HENRY L. McCLUSKEY, Secretary.....	Phoenix
HON. W. O. SWEET, M.D.....	Phoenix
HON. EVERETT E. ELLINWOOD, LL.B.....	Phoenix
HON. HALBERT W. MILLER, B.S. in Agr.....	Tucson
_____	
HOMER L. SHANTZ, Ph.D., Sc.D.....	President of the University

## EXPERIMENT STATION STAFF

PAUL S. BURGESS, Ph.D.....	Director and Dean
<b>AGRICULTURAL CHEMISTRY AND SOILS DEPARTMENT</b>	
WILLIAM T. McGEORGE, M.S.....	Agricultural Chemist
*JAMES F. BREAZEALE, B.S.....	Biochemist
THEOPHIL F. BUEHRER, Ph.D.....	Physical Chemist
HOWARD V. SMITH, M.S.....	Assistant Agricultural Chemist
ROBERT A. GREENE, Ph.D.....	Assistant Agricultural Chemist
E. OSBORN FOSTER, M.S.....	Assistant Agricultural Chemist (Phoenix)
<b>AGRICULTURAL ENGINEERING DEPARTMENT (Irrigation)</b>	
GEORGE E. P. SMITH, C.E., D.Eng.....	Agricultural Engineer
HAROLD C. SCHWALEN, B.S. in M.E., M.S. in C.E.....	Associate Agricultural Engineer
WILLIAM A. STEENBERGEN, B. S. in C.E.....	Assistant Agricultural Engineer
<b>AGRONOMY DEPARTMENT</b>	
RALPH S. HAWKINS, Ph.D.....	Agronomist
IAN A. BRIGGS, M.S.....	Associate Agronomist
ROBERT L. MATLOCK, Ph.D.....	Assistant Agronomist
*ARTHUR T. BARTEL, M.S.....	Junior Agronomist
<b>ANIMAL HUSBANDRY DEPARTMENT</b>	
ERNEST B. STANLEY, M.S.....	Animal Husbandman
EVERETT L. SCOTT, Ph.D.....	Associate Animal Husbandman
<b>BOTANY DEPARTMENT</b>	
JOHN J. THORNER, M.A.....	Botanist
<b>DAIRY HUSBANDRY DEPARTMENT</b>	
WALTER S. CUNNINGHAM, M.S.....	Dairy Husbandman
RICHARD N. DAVIS, M.S.....	Associate Dairy Husbandman
<b>ENTOMOLOGY AND ECONOMIC ZOOLOGY DEPARTMENT</b>	
CHARLES T. VORHIES, Ph.D.....	Entomologist
ELMER D. BALL, Ph.D.....	Economic Zoologist
†WALTER P. TAYLOR, Ph.D.....	Senior Research Biologist
LAWRENCE P. WEHRLE, Ph.D.....	Assistant Entomologist
<b>HORTICULTURE DEPARTMENT</b>	
ALLEN F. KINNISON, M.S.....	Horticulturist
DAVID W. ALBERT, M.S.....	Associate Horticulturist (Tempe)
MALCOLM F. WHARTON, M.S.....	Assistant Horticulturist
ALTON H. FINCH, Ph.D.....	Assistant Horticulturist
ROBERT H. HILGEMAN, B.S.....	Assistant Horticulturist (Tempe)
‡KARL HARRIS, M.S.....	Assistant Irrigation Engineer (Phoenix)
<b>HUMAN NUTRITION DEPARTMENT</b>	
MARGARET CAMMACK SMITH, Ph.D.....	Nutrition Chemist
GLADYS HARTLEY ROEHM, Ph.D.....	Associate Nutrition Chemist
EDITH LANTZ, M.S.....	Assistant Nutrition Chemist
<b>PLANT BREEDING DEPARTMENT</b>	
WALKER E. BRYAN, M.S.....	Plant Breeder
ELIAS H. PRESSLEY, M.S.....	Associate Plant Breeder
<b>PLANT PATHOLOGY DEPARTMENT</b>	
JAMES G. BROWN, Ph.D.....	Plant Pathologist
RUBERT B. STREETS, Ph.D.....	Associate Plant Pathologist
MILTON M. EVANS, M.S.....	Research Assistant in Plant Pathology
<b>POULTRY HUSBANDRY DEPARTMENT</b>	
HARRY EMBLETON, B.S.....	Poultry Husbandman
HUBERT B. HINDS, M.S.....	Assistant Poultry Husbandman
<b>RANGE ECOLOGY DEPARTMENT</b>	
WILLIAM G. McGINNIES, Ph.D.....	Range Ecologist
ANDREW A. NICHOL, B.S.....	Assistant Range Ecologist
LAURENCE D. LOVE, M.S.....	Research Assistant in Range Ecology

†In cooperation with United States Department of Agriculture, Bureau of Biological Survey.

‡In cooperation with United States Department of Agriculture, Bureau of Agricultural Engineering.

\*In cooperation with United States Department of Agriculture, Bureau of Plant Industry.

## FOREWORD

In this bulletin the author presents his views of how plant behavior should be studied to best advantage. There, no doubt, will be many who will not agree with his contention that a teleological concept is necessary, or even permissible, in plant research. It must be admitted, however, that many investigators, particularly those who are just beginning their careers, have a rather narrow outlook, and do not realize fully the importance of many of the basic factors which the author brings out. This narrow point of view sometimes leads to such errors as that of treating symptoms in place of diseases.

The discussion is largely philosophical, but based on an immense amount of practical experience and an intimate association with growing plants. The great scientists of ancient times attempted to settle all their problems by means of philosophy, and did not resort to experimental proof. As human development proceeded, and as specialization increased philosophy was gradually displaced by experimental research, until today there is possibly too little philosophy left in pure science. Philosophy in science should have its usefulness.

Philosophy in the study of Nature consists in analyzing phenomena to their simplest forms. The simplicity of basic concepts is remarkable. In this age of specialization, a man becomes a layman just as soon as he gets out of his own limited field of work. However, it is a noteworthy fact that all laymen can easily understand fundamental, or axiomatic, expression, for such is the universal language.

The author of this bulletin tries to emphasize the fact that plants have worked out many of their problems ages ago, and in the simplest and most reasonable way. It is just as logical to assume that plants have worked out their problems as it is to assume that animals have worked out theirs, as they both represent adjustment to environment. New problems are arising continually and these must be met and solved if the plant is to survive. The author points out that a plant always may be depended upon to do the most reasonable thing.

We cannot study the present or the future intelligently without some knowledge of the past. A rock formation, for example, may tell a story to the geologist, going back millions of years, but it may be of no interest whatever to one who has given no thought to such matters. The morphology, the embryology, the physiology of a plant has a tale to tell and all of our so-called biological laws are but interpretations of natural phenomena.

The author of this bulletin has a scientific background with over thirty years experience in plant research to support his statements. Whether we agree with the author or not this work should be of interest both to the layman and to the man who is engaged directly in plant research.

H. L. SHANTZ.

## TABLE OF CONTENTS

	PAGE
Introduction .....	61
Necessity of fundamental concepts.....	63
Postulates and common sense.....	64
The plant, a product of environment.....	65
Stimuli .....	67
The permanent effects of stimuli.....	69
The language of plants.....	70
Plant diagnosis.....	72
Equilibria in plants.....	74
Conservation of energy in plants.....	75
Transpiration and conservation of energy.....	76
Nutrition and adaptation.....	78
The margin of safety.....	79
Seed crops, and periods of stress.....	81
The first law of nature.....	82
Plant concepts.....	83

# Fundamental Concepts in Plant Research

BY

J. F. BREAZEALE

---

## INTRODUCTION

In the past, the study of plants has been, too often, a study of parts, and not of the plant as a unit, and the basis of such study, usually, has been the vegetative cell. From a purely technical standpoint, the study of parts might be a logical procedure, but the writer is of the opinion that the study of plants should not be limited to orthodox teachings. Plants have a real life, as well as the artificial life which they live in text books on plant physiology or ecology. This real life should be taken into consideration by every student of plant phenomena.

While it may be true that all plant research has a tendency to broaden and deepen our appreciation of the work of Nature, it often happens that a sense of beauty of the coordination of parts is partially, or wholly lost, if too much emphasis is placed upon detail. This is true in all art. A landscape painter tries to picture Nature in one of her varying moods, rather than to paint such detail as may appear in a sharp photograph.

We are taught that the "proper study of mankind is man," and that man cannot be considered aside from his environment. A plant should be studied in the same way; it is a part of its natural habitat. For untold ages Nature has been at work, rejecting and selecting her progeny, in order to produce the vegetation which now clothes the earth. This progress, although slow, has been constant, and governed always by fixed and fundamental laws. The tendency at all times has been to maintain equilibrium between all natural forces. The present, therefore, is the result of the past, and every plant now living represents something of what has gone before.

It is true that, in all research, the personality of the investigator usually determines the nature and quality of his work. It, therefore, is often a question whether an individual should devote his attention largely to the study of the plant as a unit, or to concentrate upon the details of its make-up. Some people intuitively "feel" plant response. Luther Burbank was such an individual, and there are many others. Obviously it would not be advisable for such men to devote their attention to such phases as histology, as in so doing they would be almost sure to overlook many fundamental factors. In the same way, many investigators are best

adapted to detail work, and ill adapted for all other kinds of research. However, a plant should be viewed from as many angles as possible, as there is danger of error when it is viewed from one only. As it has been tersely expressed, "It is often advisable to look at a plant with a telescope, before placing it under a microscope."

A plant, like a fine watch, is an intricate system of interlocking parts. Every part is adjusted to, and is coordinated with, every other part, and the whole is so accurately regulated that it may be considered a unit. Like a watch, a plant must be regulated in all positions. An accurate coordination of parts in one position, does not necessarily mean coordination in all positions.

A plant is finely and accurately adjusted in its native habitat only, and this adjustment is the result of long ages of adaptation. A change of environment, such as that which is often caused by removal from its natural habitat, may upset this adjustment to such an extent that the plant either may die, or else be forced to go through another long era of adaptation.

The plant is a great equalizer of forces; it is most conservative of its energy, and as economical of its resources as is possible under the conditions of its growth. It is a most reasonable system, and in agricultural experimentation it is always the last referee.

The greatest attribute of a scientist is the ability to observe, interpret, and explain natural phenomena. The power of observation and intelligent explanation do not necessarily go hand in hand. Many of the ancients had the power of observation developed to a remarkable degree, yet their explanations of observed phenomena, in the light of our present understanding, were often amusing. The power of accurate observation is now characteristic of primitive people rather than of the educated and enlightened. We have lost partially the ability to see and appreciate the beauties of Nature. Our faculties of interpretation have outrun our powers of observation, and we now have ten explanations where we have one new observation. Surely the younger generation needs some stimulus in observing natural phenomena.

In this bulletin the plant will be regarded as a unit, and only those characters which have to do with coordination will be considered. The expressions "plant language," "plant psychology," "frame of mind of the plant," etc., will be used only for lack of better terms. It must not be understood that the writer holds to the belief that the plant "elects," or exercises a will. It reacts to stimuli only.

The bulletin is not a discussion of "vitalism," but its aim is to present to the student of plant phenomena, in a homely kind of way, a few simple and fundamental facts which may enable him to undertake his inquiries more intelligently, and which may assist him in judging the "reasonableness" of his conclusions.

*A plant always may be depended upon to do the most reasonable thing.*

Some homely illustrations are given and these are drawn from both plants and animals indiscriminately. Reasoning from plants to animals, or vice versa, is not poor logic, as it is often thought to be. Both plants and animals are products of environment, they are both what natural conditions have made them, they both represent reactions to stimuli, they both reflect something of the Infinite.

The writer is not prepared to discuss exceptions. Evolution and adaptation are so complex, and there are so many unknown factors, that they should be considered from the broadest viewpoint only.

The study of plants is one of the most fascinating occupations in the world, and one which offers almost unlimited possibilities. If this bulletin will help the student to see more of what is going on around him, its mission will not be in vain.

## NECESSITY OF FUNDAMENTAL CONCEPTS

No research, whether with animate or inanimate subjects, can be carried on to best advantage without a theoretical background. Although we may know very little definitely of certain fundamentals, we must begin with one or more suitable concepts. This does not mean the acceptance of old theories, although such a course is followed frequently. A blind faith in an old theory is often more of a detriment than a stimulus to inquiry. The great scientist, Charles Darwin, discarded old theories, and his greatest service to posterity was that he gave us absolute freedom of thought in the study of Nature. His theory of evolution was subordinate; man could have gotten along indefinitely under the old theory, but Darwin showed us how to look for the "reasons why" in natural phenomena.

Many students elect, or are forced, to work empirically, that is by the system of trial and error. If interest is sufficiently strong, in time one may gain experience and gradually work out his problems in his own way, guided largely by common sense. At best, this is a slow and tedious process. A single disturbing factor, which may be unknown to the investigator, may lead to erroneous conclusions. It usually is preferable, in the beginning, to lay down one or more reasonable concepts, and to accept these without proof. If the theory is well defined and fundamental, an intelligent investigator will trust to his theory more than to his experimental work. If, for example, a chemist who is working upon gases, finds that the results of his experiment do not coincide with the kinetic theory, he knows, in all probability, that his results, and not the theory, are wrong.

*A scientist in the field of plant research may be defined as "one who wishes to know the reasons why," and one who, when*

he has observed a natural phenomenon, is not satisfied until he has formulated, or recalled, some kind of theory which explains the visible facts.

An hypothesis, to be satisfactory, must be broad enough, first, to explain observed phenomena, second, to enable the student to understand and remember facts, and third, and above all, to give the students the satisfaction of working in the light. Probably no other stimulus to inquiry is as effective as the knowledge that he is right; that is, the uplift which comes through the satisfaction of working in the light.

An hypothesis should enable the student to predict in advance what a plant may or may not do, when placed under certain environments. A chemist can do this, in his studies of chemical behavior. The physicists can do this also, for both chemistry and physics are founded upon fundamental laws. A working knowledge of chemical or physical fundamentals will save an investigator a tremendous amount of experimental work. A well-informed scientist knows in the beginning what to attempt and what not to attempt to prove.

Chemical elements arrange themselves in obedience to unchangeable laws; and the laws of plant behavior, although not so well understood, are just as definite as those which govern chemical or physical reactions. Certain fundamental properties are common to all plants, whether they are fungi or more highly specialized organisms, and whether they are native to the tropics or to the polar regions. Plant research should not be based upon the principle of trial and error, as it is carried out, in many instances, today. *The real worth of an investigator in plant behavior rests almost altogether upon the intelligence of his opinion, and an intelligent opinion, if not inherent in the investigator, can be gained only by experience, or by repetition of experimental work.* The opinion of an investigator upon any problem is usually of more value than the visible results of his experimental work, as expressed in text or tables. His opinion is probably gained by many years of experience and thousands of observations, whereas one unknown disturbing factor might mislead him in judging the results of any particular piece of experimental work. There is an urgent demand for more fundamental concepts.

#### POSTULATES AND COMMON SENSE

We begin the study of mathematics by realizing a few fundamental facts, or axioms, as for example, "The whole is equal to the sum of all of its parts, and is greater than any of its parts." The axioms are not drilled into us, as for example, are the letters of the alphabet, or the multiplication table, but they are assumed, that is, they are self-evident facts. The truth of such axioms does not depend upon observation or measurements, in fact it is often difficult to prove the truth of axioms. They rest upon common sense only.

In geometry, axioms are called postulates, and these form the very basis of this science. In solving a geometrical problem, we go back with our proof no further than the postulate. We begin with self-evident assumption, and endeavor to establish the proof of the theories either by observations or measurements. The same course of reasoning is followed in physics, in chemistry, in astronomy, or any other science. In the evolution of chemistry as a science, one of the first steps was the development of theories, or postulates, which explained certain observed phenomena. Many of these theories have become well established laws, and the postulates have been pushed further back into the fundamental.

Axioms, or postulates, are as clearly indicated in the study of plants as they are in the study of numbers, or of planes and angles, or of chemical reactions. It is just as unreasonable to expect one to progress far in the study of the likes and dislikes, of the habits and idiosyncrasies of plants, without a working knowledge of the habits of the individual, and of some of the fundamentals involved, as it is to expect to excel in geometry without the use of certain postulates. Common sense is the keynote in both cases.

The ability to grow plants successfully, and to get positive results in plant research, rests to a great extent upon the realization of plant fundamentals, or plant axioms. Such a realization may be either conscious or unconscious, but usually the latter. Some people, without evident effort, can make all kinds of plants grow successfully, but cannot explain why they are able to do this. Other people find it almost impossible to grow plants properly, no matter how much care they exercise. As has been said before, a working knowledge of plant fundamentals is inherent in some people. An investigator without this inherent character is placed at a great disadvantage, for there is no substitute for it. Measurements of green weight, dry weight, height, or transpiration of the plant may be misleading and variations due to technique may be exceedingly large. One without this inherent character must run his experiments over and over again, with as many improvements in technique as possible, until he is satisfied that his conclusions are reasonably correct. *In this way, plant research becomes partly a matter of experience and intuition.*

## THE PLANT A PRODUCT OF ENVIRONMENT

Several years ago the author attempted to define a plant as "an up-to-date living product of environment." However, this definition is not satisfactory. In the first place, it does not distinguish between a plant and an animal, and in the second place it is evident that a plant is never up-to-date.

It is probably impossible, in a definition, to distinguish between a plant and an animal. Both are products of environment, both are what natural conditions have made them. A plant is more

susceptible to influences of environment than is an animal. Most animals have the power to move from one place to another, so if an environment becomes intolerable, a migration may occur. Plants may have the power of distribution developed to a high degree, but they do not migrate voluntarily. When the environment becomes intolerable, they must either change their characters to suit the new conditions, or they must perish. Fortunately for the plant, changes in environment usually go on slowly, and the plant is often able to adapt itself gradually to the change of conditions, and thus survive. It is true that the age of adaptation ends with the present, but, if a plant reflects a response to stimuli, it must change its characters as changes go on in its environment. Therefore, a stimulus must be exerted for some time before a response is shown in the plant. The plant is not up-to-date, it always lags behind, and adapts itself slowly to changes in environment.

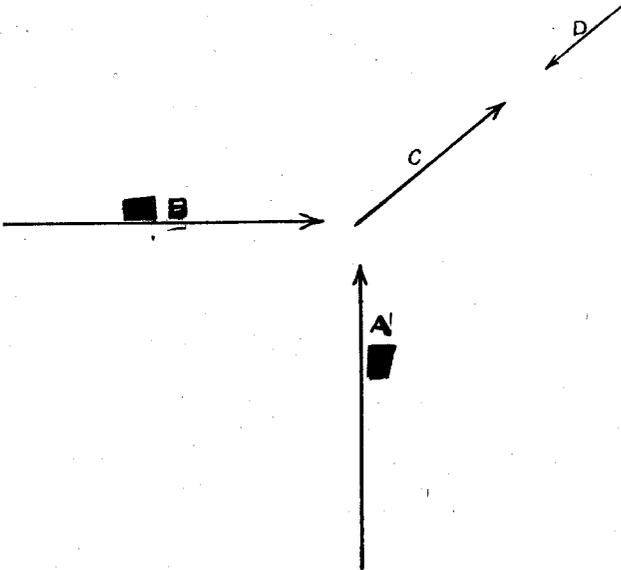


Figure 1. Vector diagram.

Recently, another definition of a plant was suggested to the author by Dr. O. C. Magistad, namely, "A plant is the vector sum of all stimuli to which its progenitors have been subjected."

A vector quantity is one which has both direction and magnitude. Let us imagine a certain body, which is free to move, being acted upon by two forces at the same time. One force, A, Fig. 1, urges it toward the north, and the other force, B, urges it toward the east. The body upon which these two forces act, will move in a northeasterly direction—C. The combined effect of the two

forces is not determined by adding the separate effects of the forces (A and B) numerically, since such a procedure would not take into consideration the difference in direction of A and B. Part of the force A is neutralized by B, and therefore is not applied to C. Again, the moving body C may meet an opposing force, probably another vector quantity, exerted in exactly the opposite direction, D. Such a force, if of lesser magnitude than the combined forces of A and B, will not change the direction of C, but it will partially neutralize the effects of A and B. If D is of greater magnitude than the two other forces, the direction of C may be reversed completely. The line C represents a vector quantity, and such a quantity takes into account all forces or stimuli which may have been previously exerted, independent of direction or magnitude. *A plant may be considered as the vector sum of all stimuli.*

### STIMULI

In terms of animal or plant physiology a stimulus may be defined as any influence that produces a functional reaction in irritable tissues. A stimulus may be simple or it may be exceedingly complex. However, when stimuli are viewed as vector quantities, their effect upon plants and animals are more easily understood. A "condition" which may be the resultant of an infinite number of stimuli, may act as incentive. A condition may include both the positive and the negative, but the stimulus comes from the positive only. If the sun shines continuously day after day as it does in Arizona, the native vegetation is in equilibrium with this condition and plants develop normally. If, however, clouds should pass over the sun and if this condition of semi-shade should continue indefinitely, plants would grow abnormally, that is, they would make an effort to reach equilibrium with the new condition. In such a case nearly all plant species would survive as there would not be a change of environment severe and sudden enough to kill them. If however, these desert plants should be placed suddenly in total darkness, they would nearly all die, because their systems would not have sufficient time to adjust themselves to such an abrupt change of conditions.

Negations, such as darkness, cold, and scarcity of plant food, cannot act as stimuli, although they seemingly do. If normal sunlight is reduced, the stimulus to the plant will be reduced also, and under such a condition most plants would elongate abnormally, or "spindle up," in an effort to get more light, and in this way attempt to make an adjustment. The change in manner of growth would be caused by the withdrawal of light and not by the negation, darkness.

With plants, as with man, necessity is the mother of invention. During the long era of animal development, the demand for two eyes was felt and two eyes appeared. If, by any chance, the necessity for two eyes should disappear, one of the eyes would

gradually disappear. In ancient times the ancestors of the horse had five toes upon each foot. The necessity for five toes disappeared, due to conditions which are unknown to us, so the animal of today uses only one toe upon each foot, with four other toes still remaining as rudiments on and above the fetlocks. If the necessity for sight should disappear altogether, both eyes would probably gradually disappear.

It is difficult to conceive of the appearance of a character in a species without the demand for such a character existing beforehand. It is equally difficult to conceive of a character remaining indefinitely after all the stimuli which produced this character have disappeared. Time is long and Nature has infinite patience. If a million years is required to produce a hereditary character, it is unreasonable to assume that such a character may be discarded in a few generations.

Characters sometimes appear as mutations or otherwise, which are distinctly disadvantageous to survival, as, for example, albinos among coyotes. While it is not the object of this discussion to evaluate such exceptions, it may be said that it is possible that at some remote date all coyotes were white, but in the course of time their color has changed to a neutral gray, which is the most protective color possible on the desert. This recessive character might have been carried latent for hundreds of thousands of years and now reappears only upon rare occasions. If the sands of the desert should gradually turn white, it is probable that a million years hence a neutral gray coyote might appear upon rare occasions, as a mutation among a population of snow-white individuals.

Many geneticists work upon the theory that mutation and the appearance of new characters are purely accidental. The writer is of the opinion that there is nothing accidental in Nature. Mutations may be reactions even to suggestions which cannot be seen or evaluated.

Citations are made often, which apparently show how a character may be developed in response to a stimulus, and after the stimulus has disappeared, that said character may continue to develop until it may actually prove detrimental to the individual. The horns of the stag are cited as a familiar example. These horns were developed, unquestionably, as a means of protection, but they have long ago outgrown their usefulness.

It is barely possible that, in certain cases, the arguments to support such a theory are tenable, but probably not so in the case of the horns of the stag. These horns were probably first developed as a protective character, but when they reached the length and shape of those of a Devon bull, they were at their maximum efficiency. They might have stopped developing in size here, but a new and more potent stimulus appeared. The female saw those horns, and they looked good to her. They suggested strength and prowess, and thereafter, for mates, she began to select those males with the longest and most graceful antlers.

The final result of such a long continued selection is a pair of antlers, symmetrical and beautiful to look upon, but practically worthless as a protective character.

If other cases of development of abnormal, or useless, characters could be analyzed critically, they too might be readily explained. However, the results of natural selection are easily seen, even though often difficult to explain.

#### AFTER-EFFECTS OF STIMULI

Certain stimuli must be exerted over a long period of time before their effects become manifested visibly. When once established however, all stimuli leave their effects upon both plants and animals. A certain stimulus might have been exerted ages ago, it might have been neutralized partly, or the stimulus might have disappeared altogether, but its effects linger *ad infinitum*. Hundreds of cases could be cited.

In the days of chivalry gentlemen wore coats of mail, metal helmets, and gauntlets for protection. In order to show his trust in anyone, a knight would remove his gauntlet from his right, or "sword," hand, take off his helmet and bow his bare head, thus placing himself at the mercy of the one to whom he wished to show respect. We still retain the custom of uncovering our heads and offering our right hand as a token of respect.

In Norway, at certain seasons of the year, flocks of land birds fly out to sea and are drowned. This phenomenon cannot be explained in the light of present-day conditions. It has been suggested that, at some remote time, an island stood in this neighborhood, which offered a resting place, or perhaps a nesting place, for the birds. The island has long since disappeared, but the stimulus to fly in this direction is still instinctive.

There are many cases of migration of rodents which may be explained in this way. The well-known case of the leming may be cited. These little animals, which are about the size of rats, live in the highlands of Scandinavia, in Greenland, and in the northern part of Canada. They multiply very rapidly, but at irregular intervals; they migrate in great numbers, sometimes as far as one hundred miles. If they come to the sea, or a large body of water, they plunge into it and are drowned.

Many biologists explain these migrations as being caused by over-population in their native habitat, but such an explanation is not satisfactory. These migrations occur at practically the same time in Scandinavia, Greenland, and Canada, and it is very unlikely that over-population should take place in each of these countries at the same time. It is more probable that the migrations are reactions to certain stimuli which are unknown to us, but which the ancestors of lemmings felt. The present generation in Greenland, Canada, and Scandinavia are probably descendants of a common stock and each has inherited the instinct to migrate.

The stimuli of migration are of such a nature and probably of

such great age, that they never may be thoroughly understood. However, there are many effects of past stimuli, both in plants and animals, which may be explained easily, and satisfactorily; and such explanations often give us accurate information concerning the conditions under which the plant or animal developed and of the conditions which are now suitable for the normal development of the individual. Some plant manifestations of early conditions will be discussed later.

These inherited traits, or "left over" characters, are so common in plants and animals and are of such importance economically, that, *in plant research, it is always best to find out, if possible, how and when and where the plant's ancestors lived, before beginning a study of the needs of the present generation.* Every phenomenon of plant growth and plant nutrition that the writer has observed in the past thirty years, is but a phenomenon of adaptation.

The realization of this fact has been a wonderful help in plant research. In the study of alkali tolerance, for example, much time has been wasted in determining the toxicity of haphazard mixtures of salts upon plants. The degree of toxicity of all salts has been established ages ago by all plants. This varies in degree with each plant, but is fundamentally the same for all, in that the toxicity is determined by the units of times that the plant has come in contact with that salt, or a like salt, during its era of adaptation. If the plant has met sodium chloride one thousand times, and copper sulphate one time, during this era, copper sulphate will then be one thousand times more toxic than sodium chloride. If we only knew all of the conditions to which a plant has been subjected during the past ages, we could predict with certainty the behavior of a plant under a certain set of present-day conditions. The reverse of this is true also, if we observe accurately the behavior of a plant under present-day conditions, we can interpret intelligently what must have been conditions in its native habitat during its age of adaptation. This applies to other characters such as drought- and disease-resistance, as well as to alkali tolerance.

*In all matters of nutrition, water assimilation, tolerance to alkali and all kindred phenomena, the plant has worked out its problems ages ago, and in the most reasonable way.* Plant phenomena are always simple, although we may strive strenuously to make their interpretations as complex as possible.

## THE LANGUAGE OF PLANTS

Language is not a character which is inherent in *genus homo* alone. Many of the higher animals have a well-defined language. A dog, for example, expresses his feelings with quite a number of different articulate sounds. Not only this, he understands the language of his master, probably much better than his master does his. A chicken has six or eight words, while a giraffe has none.

An enlightened linguist can express his thoughts with a great number of words, probably fifty thousand, although he may not use one-tenth of this number in ordinary conversation. Certain tribes of our American Indians, the Pima or Papagoes, for example, have only about one thousand words altogether, while the Hopis have only a few hundred, and use ordinarily, only a fraction of these. Some of the primitive tribes of Africa or Australia have very few words. In comparison with a fluent linguist, a dog expresses his feelings with relatively few sounds, yet in all probability there is less difference between the language of a dog and that of an Australian bushman than there is between the language of the bushman and that of a fluent linguist.

As the number of words decrease, the number and importance of signs, or gestures, increase. These are often more expressive than words. As animal species shade into plant life, sounds are eliminated altogether, and acts alone express reactions to stimuli. All plants react to stimuli. Plants have a language which is all their own, they have their likes and dislikes, and their idiosyncrasies. By their acts they are always ready to tell many facts, particularly of things which took place long before the dawn of history. Plant language, while not articulate, or while not even a sign language, is simple and expressive when once we know how to interpret it. We often misunderstand plant language.

A short time ago at a small scientific meeting a statement was made about plant language and the possibilities of its meaning in plant research. In this era of lawlessness it is quite natural that men's minds should turn toward crime suppression, so one of the audience made the remark that, as it seemed very hard to suppress crime by ordinary methods, it might be possible to use plants as "crime detectors." The remark was, of course, made in jest, but a few nights before, a very amusing incident had occurred, which was related. The writer had been germinating some wheat seedlings and had several culture pans with a few thousand seedlings, about five days old. The plant laboratory of the University of Arizona adjoins a chemical laboratory, which at that time was occupied by a graduate student, and only a glass door separated the rooms. Upon the evening in question, when the laboratory was closed for the night, the shades of all the windows were pulled down, and the seedlings left upon a shelf in the center of the room. In the morning, all the little seedlings were found bending in the direction of the glass door of the next room. After a while, the student assistant came in and was surprised to be told that he had been in the adjoining room on the night before. He admitted this and looked puzzled. He was told further that he had been in the chemical laboratory for at least an hour. He admitted this accusation also, and wished to know how it was found out. He was then shown the little seedlings all pointing toward the glass door which admitted the light from the other room. The writer has had many

other experiences like this one, so it may be said definitely that plants may be used as "crime detectors."

When an orange seed is planted, if the soil is kept warm and moist, the little seedling will come up soon, but if exposed to the direct rays of the sun, it will be killed. However, if partly shaded, the roots will grow downward, and then upward toward the surface of the soil. If a mulch of organic matter, such as decayed leaves, is placed around the plant and kept moist, the roots will grow into the mulch and form a thick mat near the surface.

This is what the little seedling is telling us. "In my native habitat, I lived in a warm country, probably warmer than Arizona. I did not germinate in the open, but I sprouted and grew in semi-shade, probably beneath some large tropical tree. I grew as an under brush, and I fed upon the leaf mulch which was dropped by the large tree."

### PLANT DIAGNOSIS

In agriculture as an applied science, the psychology of the plant should be taken into consideration, and its language should be studied and understood. The plant will tell what its great-great-grandfather did for a living, and what is wrong with its present environment, if its reactions are studied. A child suffering from rickets has distinct symptoms, and these usually are diagnosed readily. The child does not necessarily need food, it needs vitamins A and D, and it is given cod-liver oil and yeast, as these contain the limiting factors. The child does not tell you of its needs by word of mouth, but its needs are diagnosed from symptoms. A successful physician must first be an accurate diagnostician, and this character often is inherent in the individual. In all cases of malnutrition of plants there are distinct symptoms. The successful farmer often is an accurate plant diagnostician, although he usually is not aware of the reasons why and how he does it. If success is to be measured by maximum crop yields, there is no character which goes to make a successful farmer equal to that of the ability to diagnose the needs of the plant by observing its habits of growth, and its symptoms of distress.

In the case of the orange seedling just described, it was observed that the germinating seedling was killed by exposing it to the direct rays of an Arizona sun. This indicates that the orange tree will grow best in semi-shade. While it may be impossible economically to grow such a crop in shade, it has been demonstrated repeatedly that cheese cloth tents increase citrus production markedly. It is also the common experience that the seed bed should be under a slat roof.

The roots of the seedling grow downward, then they turn upward toward the surface of the soil. In its native habitat there probably was a leaf mulch, and an acid medium for the feeder roots. The farmer can imitate this by a mulch of manure, or

other organic matter. He often does this, and in order to economize with the mulch, he usually protects it by covering it with a layer of soil. Although much good often may be derived from the use of inorganic fertilizers, no such commercial fertilizer can accomplish the same effect as manure or active organic matter does upon citrus. Decomposed organic matter imitates the natural habitat of the orange, it contains the plant vitamins which are the limiting factors in quality and crop yields.

By observing the likes and dislikes of the seedling, the orange grower can imitate natural conditions as far as economically possible. An orange tree that is suffering from malnutrition shows its distress by "mottling," by "little leaf," and in many other ways. This would not happen under normal conditions of growth. If there is a limiting factor, no amount of the so-called plant foods, or of scientific care or cultivation, can remedy this condition, as long as this limiting factor remains. The normal condition of growth is that condition under which the plant lived during its era of adaptation, and the present-day plant is demanding that condition which its progenitors were subjected to. *The natural way usually is the best way.*

An anemic tomato plant, growing in a soil which lacks available phosphorus, makes a stunted growth, it has small, badly-shaped leaves, which have a peculiar blue-green color. The symptoms of phosphate starvation are unmistakable, and no amount of nitrogen or potash will remedy the situation so long as phosphorus remains the limiting factor.

An alfalfa plant, growing in a soil with little nitrogen, makes a poor growth, its leaves are yellowish-green, and it goes to seed early. It has been shown by Hoffer<sup>1</sup> that a corn plant which is suffering from a deficiency of potash has chaffy ears on prematurely broken shanks and large stalks with rotten roots. The plants have a tendency to die early. Corn plants suffering from phosphorus deficiency have normal green leaves, but make stunted growth and often a poor stand upon acid soils.

W. P. Naquin and W. T. McGeorge have observed that sugar cane behaves very much like corn. A potash deficiency is indicated by a premature death of the lower leaves. The leaves wither and die around the margins, due to the withdrawal of the potassium from this area in order to supply the demand of the growing parts.

It is not the aim of this bulletin to discuss in detail the symptoms which are associated with distress of plants, but only to show the possibility of detecting their nutrient deficiencies by observing their color and habits of growth.

Certain crop plants show symptoms more forcibly than others, and such plants often may be used to advantage as indicators. An orange tree, for example, may react very slowly to a deficiency of phosphorus, while a tomato, a lettuce, a squash or a mil-

<sup>1</sup> Hoffer, G. N., 1926. Testing Corn Stalks Chemically to Aid in Determining Their Plant Food Needs. Purdue Univ. Agr. Exp. Sta. Bul. 298.

let plant may react in a few weeks. Such plants as these often may be grown in the same field as the main crop, and observations made upon these "symptom plants" may be applied to the major crop. If we cannot understand the language of the main crop, we should employ an interpreter.

The writer has used blue-green algae upon many occasions as an accurate indicator of the presence or absence of soluble phosphorus in the soil. These little plants are exceedingly sensitive to phosphorus. The farmers in the Middle West know this, and their best corn fields always show a good growth of algae in the damp and shady places. If there is not enough phosphorus in a soil to support the growth of a tiny plant like algae, it is safe to assume that there is not enough for a crop like corn, alfalfa, or citrus.

It is true that many like symptoms are common for several forms of distress. This is true in human medicine also. However, there are many distinctive symptoms, or combinations of symptoms, which offer valuable leads in diagnosing the many ills with which crops are afflicted. This field of research offers many possibilities, both in University training and in the science of applied agriculture.

### EQUILIBRIA IN PLANTS

Plants are in a state of equilibrium, or balance, with all fixed forces, but they are in a condition approaching equilibrium, that is, in dynamic equilibrium, with all variable forces. Gravitation, cohesion, adhesion, and chemical reactions, are examples of fixed forces. These are governed by fixed or definite laws, which always have existed, and always will exist. Climatological and biological forces are variable. These are seldom the same, even from day to day.

In such matters as nutrition and water assimilation, the plant operates in equilibrium with definite laws, therefore such traits are fundamental and fixed. The mineral nutrients in the soil solutions ionize with definite constants. They have always done this, and they always will. The plant developed under these conditions, and surely it is in equilibrium with them. It must of necessity absorb the ions as it finds them in solution. On the other hand, in the development of color in flowers, the plant is dealing with insect appeal, and this, as well as all other biological factors, is changeable. Certain pollinating insects, to which one set of colors may appeal, may be exterminated, and other insects may appear which demand another color scheme. The peculiar structure of a flower may cause pollination by the entrance and exit of a particular insect, and this insect may be exterminated. The plant either must change the color or the arrangement of the flower, or perish, and if the stimulus is applied slowly and gradually, it will respond to the stimulus and change the color or shape of the flower. The plant breeder may find it a relatively

easy task to alter the size, shape, or color of the flower, but in matters of nutrition or water absorption, it is well-nigh an impossible task. The latter characters cannot be changed unless the entire mechanism of the plant is changed. *The stability of characters within the plant is a function of the length of time that such characters have been inherent within the plant.*

## CONSERVATION OF ENERGY IN PLANTS

We read of the "extravagance of Nature," but there is no truth in such a doctrine. The plant exercises the maximum amount of conservation in the expenditure of its energy as is reasonably possible under the conditions of its growth. Plants are economical in every respect. They do only the work which is necessary in the perpetuation of their species, and at all times every precaution is taken by means of protective characters to avoid unnecessary expenditure of energy.

The law of the survival of the fittest is infallible, whether in business or in biology. The economical plant must hold an advantage over the extravagant one in much the same way as the systematized, and business-like firm has an advantage over the unbusiness-like and extravagant firm. In either case, when periods of severe stress occur, the economical plant or firm will survive while the other may perish. *Of all the factors which are concerned in the plant's development, and in the origin of species, the conservation of energy is one of the most important.*

Conservation of energy in plants is much like system in business. System may be defined as a scientific adjustment of time, resources and energy. It is almost impossible to economize effectively in all of these essentials at the same time. For example, in order to gain time, it is often necessary to use a liberal amount of energy, or to employ more than ordinary amount of resources. Economy, or conservation, consists more in the adjustment of these essentials to each other, than in the frugal use of either or all.

In nearly all enlightened countries labor is expensive, and therefore, whenever possible, machinery is introduced as an economical measure. However, in sections of the Orient, labor is very cheap, and machinery is expensive, and therefore it is actually extravagant to use machinery.

In order to maintain the proper margin of safety which is required to insure the preservation of species, many plants and animals are apparently extravagant, but not so in reality. This fact has given rise to the popular opinion regarding the extravagance of Nature. Many individual plants produce tens of thousands of seeds each year, and many of the lower animals are very prolific in the production of eggs or young. There is, however, a distinct and direct ratio between the number of seeds, eggs or young produced, and the probability of the progeny reaching maturity. The salmon may spawn an enormous number of eggs, and

these may hatch out a high percentage of little fishes, but the mother salmon does not protect her young, and only a small percentage reach maturity. When characters of protection such as mother love, appear in a species, the number of offspring decrease rapidly. The mother whale nurses and fights for her young, and while she may have only one offspring every two years, this offspring, under natural conditions, will probably reach maturity.

The eucalyptus tree produces an enormous number of seeds, while the coconut produces only a few. The eucalyptus seeds are small and poorly protected, very few germinate, and still fewer reach maturity, while the coconuts are so well protected that they may be carried from one country to another in the water of the ocean, and still retain their vitality. The eucalyptus is really not wasting its energy in seed production, it is as economical as possible, consistent with the perpetuation of its species. Under natural conditions every plant is finely adjusted, and every factor of growth is used to best advantage.

### TRANSPIRATION AND CONSERVATION OF ENERGY

There has been much discussion as to the value of transpiration to plants. The writer has shown repeatedly that wheat plants, when grown in nutrient culture solutions in the warm open air, do not absorb any more nutrient ions, nor do they make a greater vegetative growth than do plants of the same age when grown under glass, in a humid atmosphere. The transpiration of the plants in the open may be ten times greater than those under glass, but the difference in growth is usually in favor of the latter. Evidently, under such conditions, the excessive amount of water which is transpired by plants grown in the open air, is not necessary to normal development. But this phenomenon does not tell the whole story, and one cannot pass judgment upon the effects of transpiration by such superficial observations. Considered fundamentally, transpiration must be an economical process; if it had not been such it would have been modified or eliminated in great part ages ago by tropical and succulent vegetation. Desert vegetation has done this during its era of adaptation, for upon the desert, water is the limiting factor. A plant's most noticeable economy is shown usually in the limiting factor. In the greater part of Arizona the limiting factor is water, otherwise the desert soils would be wonderfully productive. Nearly all of the distinctive adaptations of the native vegetation of the State, therefore, are concerned with water conservation. Water storage in many plants has been developed to a remarkable degree and transpiration has been reduced to a minimum. Vegetative growth is also much impeded.

On the other hand, in the humid tropics or in the humid regions where there is a regular and abundant rainfall, the native plants are not concerned with water conservation. Transpiration is therefore very great and vegetative growth abundant. It would

be as unreasonable to assume that a tropical plant should be economical with water, as it would be for an Eskimo to be economical with ice. Humid tropical plants have never felt the stimulus of water shortage. Desert plants, on the other hand, are economical with water from necessity and not from choice.

It is really economical for a humid tropical plant to be extravagant with water. A high rate of transpiration from the leaves will keep a plant cool and it will cause a movement of water in the soil in the direction of the root. This will carry the dissolved soil nutrients to the absorbing zone of the root, otherwise the root would have to grow to the nutrients. Almost without exception, desert plants have a relatively large root system.

A constant movement of water in soils, especially in soils at near the saturation point, is essential for the growth of most plants. The loss of water from the soils of the humid regions is due largely to the transpiration of plants growing upon the surface. Water movement or moisture fluctuations in the subsoil causes aeration, bacterial activity, and carbon dioxide production. With the exception of the movement of water which is caused by gravity, practically all movement of moisture in the subsoil is due to the transpiration of plants.

The phenomenon of transpiration is fundamental and economic, and the stimuli which produce such activity cannot be explained upon superficial manifestations.

It has been shown fairly definitely that the carbon dioxide which is given off by the roots of plants is either in solution or in combination with water. It is probably not exuded as a gas. In the same way, in the process of absorption of carbon dioxide by leaves, the gas of the air must be first dissolved in water before it can be taken in and used by the plant in building up carbohydrates. In other words, absorption of carbon dioxide by leaves would be practically impossible without the agency of water. Even when the surface of the leaf is dry, and the internal cellular structures moist, the carbon dioxide must diffuse as a gas through the dry structure and then unite with or be dissolved in water before it can be assimilated. Ordinarily diffusion is a slow process. However, when the plant is transpiring freely, the cavities of the stomata are practically saturated with moisture, and there is a film of water covering a great part of the absorbing surface. This would render the absorption of carbon dioxide a relatively easy matter.

Absorption enables a plant to maintain turgor, and transpiration keeps the tissues cool, and it performs other functions, which are probably of minor consideration. Plants like alfalfa would not transpire as much as three thousand pounds of water in order to produce one pound of dry matter, if transpiration was not a necessary process. *A plant may be depended upon to do the most reasonable thing.*

## NUTRITION AND ADAPTATION

During the past two decades we have learned that many of the ailments of both man and the lower animals are primarily nutritional. In many cases these nutritional diseases are caused by the absence in the food of certain organic compounds which we call vitamins. Rickets in children, and scurvy may be cited as examples. Both of these diseases yield readily when the patients are given foods which contain the necessary vitamins A and D. Roup in chickens, which was formerly supposed to be an infectious disease, is now known to be caused by a deficiency of vitamin D. It may be cured by a balanced ration which contains green alfalfa, as a source of the necessary vitamin.

In 1906, two years before the word "vitamin" was coined, the writer demonstrated the fact that plants were stimulated by applications of small amounts of certain organic compounds which are not ordinarily considered as plant foods and which are found in decomposed organic matter such as manure, alfalfa or other leguminous plants. These stimulants were found to be effective in very small amounts. Badly mottled citrus seedlings and chlorotic coffee plants will burst into new growth when given small doses of these vitamin-like substances. Further investigation has led us to believe that, in a few years, we shall recognize that plant vitamins are as important in plant nutrition as are the present known vitamins in animal nutrition. These plant vitamins will not necessarily be vitamins A, B, C or D, but nevertheless they will be associated with the growth of the plant, its resistance to disease, and with the reproduction of its species.

In matters of nutrition neither plants nor animals have a very wide range of adaptation. A man can endure great extremes of heat or cold; his life may include luxuries or hardships of many kinds, yet he may survive. However, he will soon die if one or more of the necessary vitamins are deficient in his diet. The same may be said of plants. Plants in this respect obey the laws of all living organisms. Unnatural foods produce abnormal conditions. The necessity of the presence of vitamins in our foods today is purely accidental. The vitamins are essential for the reason that they were present in the foods of our ancestors during the many ages of adaptation. Had vitamins A, B, C, D or E been absent in the food of our forefathers they would not be necessary in our diet. A rat will collapse when fed upon white corn meal alone while a corn-meal worm will wax fat upon the same diet. The grandparents of the rat had a diversified diet while those of the worm did not.

Plant growth is dependent upon an innumerable number of factors, any one of which may become the limiting one. The whole list of vitamins would not be effective if available phosphorus, for example, was absent in the soil. On the contrary, if a necessary plant vitamin is absent in the soil, no plant will

function normally no matter what cultural or fertilizer treatment is given it. In such a case there is only one remedy, and that is the application of some active organic matter, an organic compound to which the plant has become adapted during its era of adaptation. It is probable that many diseases of plants may be treated more effectively when the "reasons why" are considered more seriously. Plants are only what natural conditions have made them, they reflect the conditions of their native habitat.

### THE MARGIN OF SAFETY

One of the most pronounced plant fundamentals is this: "A plant lives for one purpose only, and this is to perpetuate its species." In seed and fruit production, a plant works upon a definite margin of safety; ordinarily, under natural conditions, it produces only enough seed or fruit to maintain this margin, and thus to perpetuate its species. This margin may appear to be very large, if we think of the term in the light of business or stock market transactions, but it is never larger than necessary. When a plant reacts to the stimuli that everything is normal, and that the existence of the species is not in danger, the stimulus is not to expend surplus energy in seed production. Under ideal conditions with respect to environment, and when no periods of stress occur, the energy of a plant is expended largely in the production of vegetative tissues. There is evidently a reflection in the economy of the plant that the first essential to the permanence of species is stamina and vigor of vegetative parts.

On the other hand, when a plant reacts to the stimulus that the existence of the species is threatened, it will increase seed or fruit production. The size of the fruit may be small and the quality poor, but the number and vitality of the seeds will be of utmost importance. An orange tree that has been injured by gophers will often produce a large amount of seedy and inferior fruit. A barren apple tree may be brought into bearing by severe pruning, or by lacerating the trunk or limbs. In fact, any scheme which will give the tree the stimulus that the existence of the species is threatened, will increase seed production. The orange grower withholds water from his grove while the trees are laying down buds for the next season. The trees feel the stress and lay down fruit instead of vegetative buds. When water is applied to a grove after a severe drought, it should be done carefully or the trees may react and throw off a part of the fruit under the stimulus that it is not necessary in the perpetuation of the species. The June drop of citrus and the shedding of cotton often may be attributed to this fundamental cause. There may be physiological factors which actually bring about the drop of the fruit, but the fundamental reason for the phenomenon lies in the "frame of mind" of the plant. In the language of S. H. Hastings, "A plant must be kept in the right frame of mind."

The superficial reason for the shedding of cotton may be the

formation of a thin layer of cells of a certain type, between the stem and the fruit, which layer causes fruit to be separated easily, but oftentimes at least, the plant would not lay down this layer of cells if it had not received the stimulus that the fruit to be discarded was not needed in the perpetuation of the species. The layer of cells, which has a particular function, may constitute the mechanism of separation only, and have no other important function. The cells may be also only the visible sign or symptom of distress. The cause is more deep-seated.

It must not be understood that the writer discounts the value of investigational work upon such symptoms. Work of this nature may be very valuable, especially if symptoms are recognized as such. It should be borne in mind, however, first that several fundamental causes may be marked by one and the same symptom, and second that corrective measures should be aimed at the cause and not at the symptom.

In the case of the shedding of cotton, the drop may occur when a heavy rain falls after a long drought as it does in many places in the South, or it may occur when a sudden and severe drought follows a wet season. In every case, the shedding probably represents the effort of the plant to bring itself into equilibrium with new conditions. If a cotton plant has set a good crop of squares, or young bolls, and a severe drought occurs or hot winds blow, the plant may first throw off its fruit in order to save itself. If the stress continues, the leaves may even wither and drop off, but still the plant may survive, and, under improved conditions it may grow a new set of leaves and another crop of fruit and thus perpetuate the species. Probably the plant sacrifices first, that part of its system which can be most easily dispensed with. Some desert plants, the ocotillo for example, defoliate regularly during periods of drought.

Thus it may be seen that the shedding of fruit may be either an indication of a healthy condition of the plant, as when the fruit is shed when the plant bursts into vigorous growth, or it may be a symptom of distress, as when the fruit is dropped during a drought or when hot winds blow. It is plain that any one remedial measure would not be likely to be beneficial in both cases.

There are other factors which may bear upon the effect of soil moisture upon fruit shedding which should not be overlooked. If we assume that the shedding is produced by some kind of a stress, as excessive transpiration, or loss of water by the plant, it naturally follows that an irrigation at this time would relieve the stress.

There are many ways in which the addition of water to a moist soil may be beneficial to a plant, but it will scarcely be safe to assume that the addition of water to a soil which already has a supply of available moisture in all parts of the root zone would relieve a water stress in the tissues of the plant. If the optimum moisture content of a soil is 18 per cent its wilting point would

be about 9 per cent. It has been shown by Veihmeyer that a plant can absorb water from such a soil at 12 per cent almost as readily as it can from the same soil at 18 per cent. The real stress occurs near the wilting point. This phenomenon, as should be expected, from the nature of the curve by Schull, shows that the attractive force of a soil for water increases very little, relatively, as the percentage of moisture is decreased from optimum to near the wilting point. In other words, a plant will not expend much more energy in extracting water from the soil at 12 per cent, than it will from the soil at 18 per cent. Therefore, theoretically, the application of water to a soil which already contains available moisture, will be of doubtful value in relieving a sudden water stress in the plant. However, beneficial effects may be shown if a portion of the soil which contains roots has been reduced to near the wilting percentage.

The writer often has seen, in Southern California, orange groves defruited almost completely by hot, dry winds which blow from off the Mohave desert. When such a stress occurs, it makes little difference what soil conditions are with respect to moisture. The stress is so severe that the trees take heroic measures to meet it. A plant is almost sure to accept the lesser of two evils, and in times of stress, to take the line of least resistance.

*One of the most common errors in plant research consists in looking for superficial reasons, instead of searching for fundamental causes.*

## SEED CROPS, AND PERIODS OF STRESS

Many seed and fruit crops cannot be grown successfully without certain periods of stress. Such periods usually come about naturally during the growing season in the form of droughts, or abrupt changes in temperature. The farmer, however, often creates them by his systems of tillage, fertilization or irrigation practices. The effect of a stress period is due to the fact that the plant is given the stimulus that the existence of its species is threatened, and the plant then increases its margin of safety, and either puts on more fruit, or it retains the fruit which already has been set.

The farmer has learned by experience that Nature's way is the best, and in dealing with certain economic problems, such as the shedding of cotton, or in the treatment of barren fruit trees, he unconsciously asks himself: "How would Nature treat this plant if she wished it to hold on to its fruit, or if she wished it to produce heavily?" The answer is evident—Nature would throw some mild stress period into the life cycle of the plant.

It is not the intention of the writer to advocate any stress periods which could be used by the farmer under such conditions, but only to direct attention to the fundamental character of the situation. Theoretically, a severe root pruning, which might be done by deep plowing, or a pruning of some of the

vegetative growth above ground, which would cause a bleeding of the sap, might cause the plant to "change its mind," and to hold on to its fruit.

In the South, it is well known that the cotton plant, when grown under ideal conditions with respect to plant food, heat and moisture will not produce maximum amounts of seed or lint. It will grow into a large and vigorous plant with an abundance of foliage, but often with little fruit. In fertilizing cotton, we usually apply small amounts of nitrogen, and large amounts of phosphorus, that is, more phosphorus and less nitrogen than that demanded by the plant. It is well known that large amounts of phosphorus shorten the life of a cotton plant and hasten maturity by as much as two weeks. On the other hand, nitrogen will lengthen the life of a plant. Phosphorus stimulates fruit production which is the criterion of the cotton crop. The farmer makes nitrogen the limiting factor. There is much more to be considered in planning a fertilizer application than the mere plant-food requirements of the plant.

The "psychology" of the plant must be taken into consideration, not only in fruit and seed production but also in vegetative growth. Alfalfa, for example, is grown largely for forage; therefore, in order to obtain maximum tonnage, ideal growing conditions should be maintained throughout the growing season and all periods of stress avoided. It is well known that, if periods of stress do occur, alfalfa will make a premature effort to reach maturity, and will produce seed. Under ideal growing conditions we get maximum vegetative growth and minimum seed production.

As mentioned before, the factors which influence reproduction are changeable and therefore may be modified easily by the plant breeder. Shamel, in his bud selection work in Southern California, has developed strains of citrus which are exceedingly prolific. By his selection, he has probably given the plant the stimulus indicating that the existence of the species is jeopardized, and therefore the trees bear abnormally large crops. He is probably stimulating fruit production at the expense of stamina and permanence of species. Such is the practical and economical way of handling the situation.

### THE FIRST LAW OF NATURE

It is a noteworthy fact, that a plant is more concerned with the species than with the individual. The same thing is true with man and most of the lower animals. Self defense is not the first law of Nature as is often supposed. A man will sacrifice himself for his offspring, his family, his tribe, his community or his country. This is the natural order of things. The permanence of species depends largely upon association and cooperation. If man had not banded together in tribes or families, he probably would not be here now to tell the tale, for attempting to exist

isolated as an individual or in pairs, he would soon have perished. A lone wolf will be overcome, but a pack of wolves will survive. Wolves will compete with each other in the most severe way, but they will unite and work in harmony in a pack. Honey bees do not work in obedience to the will of a queen, but they are directed by the "spirit of the hive." A bee thinks very little of the individual; she stores up food which she will never use, and she is willing to sacrifice herself for the good of the hive.

The same is true with most plants. When the citrus tree, for example, is placed under stress, as by root pruning by gophers, it will produce a large amount of fruit. However, when the tree is placed under another kind of stress, as in competition with other trees when planted too close together, it spindles up and does not produce much fruit. In the first case, the existence of the species is threatened, but in the latter case, the individuals are too numerous. The margin of safety will be increased in one and decreased in the other.

Theoretically, a scarcity of plant food in the soil will not be a stimulus for excessive seed production. The stimulus would reflect the hopelessness of the situation, the inability of the plant to grow without proper nutrients, and the reaction would be toward the reduction of the number of individuals. Two plants cannot always grow where only one grew before, and the margin of safety must be altered to suit the occasion. *Perpetuation of species is the first law of Nature.*

### PLANT CONCEPTS

1. The greatest attribute of a scientist is the ability to observe and interpret natural phenomena.
2. One of the most common errors in plant research consists in looking for superficial reasons instead of searching out fundamental causes.
3. In all matters of nutrition, water absorption, tolerance to alkali, etc., the plant has worked out its problems ages ago, and in the most reasonable way.
4. A plant always may be depended upon to follow the line of least resistance.
5. Every phenomenon of plant growth is but a phenomenon of adaptation.
6. The toxicity of any salt is proportional to the number of units of time that the plant has come into contact with that, or like salts, during its age of adaptation.
7. The stability of characters within a plant is an index of the length of time that such characters have been inherent in the plant.

8. Plants are in a state of equilibrium with all fixed forces, but in a condition approaching equilibrium, or in dynamic equilibrium, with all variable forces.
9. In seed and fruit production, a plant works upon a definite margin of safety.
10. In seed and fruit production, periods of stress largely determine crop yields.
11. A plant lives for one purpose only, and this is to perpetuate its species.
12. Perpetuation of species is the first law of living organisms.
13. A plant exercises the maximum amount of conservation in the expenditure of energy as is possible under the conditions of its growth.
14. In order to yield dependable results in an experiment, a plant should never be subjected to a greater stress than it has met during its age of adaptation.
15. A plant may be considered as the vector sum of all stimuli to which its progenitors have been subjected.
16. It is always best to first find out, if possible, how and where a plant's ancestors lived before beginning a study of the needs of the present generation.
17. Success in plant research depends largely upon experiences and intuition.
18. In all agricultural experimentation, the living organism is always the last referee.

#### ACKNOWLEDGEMENT

The author wishes to thank his many friends for helpful suggestions during the preparation of this manuscript, particularly W. E. Bryan, T. F. Buehrer, Hermann Krauch, W. T. McGeorge, Walter P. Taylor, E. S. Turville, H. L. Shantz, and Gordon Surr.