Chapter 40

THE INTERFACE BETWEEN PLANT PHYSIOLOGY AND GENETICS

Jerry E. Quisenberry
USDA-ARS
Lubbock, Texas

INTRODUCTION

When a researcher attempts to interface the plant physiology and plant genetic disciplines, he or she is immediately confronted by "jargon" from both disciplines. Jargon is defined as "obscure and often pretentious language marked by the use of an unnecessarily large number of words to express an idea or the technical terminology of a special group or activity." Before an effective dialogue can take place between researchers in the two disciplines, terms used by each discipline must be defined in such a way that they clearly relate what each discipline is trying to express. We must constantly recognize that if we expect our research to be used, our results should be clear to our prospective "user" and to cooperating researchers from various disciplines.

PLANT PHYSIOLOGY

Plant physiology is "the study of plant function." This definition does not exclude plant structure, but it places the primary emphasis on plant function. The basic study of plant function has been a very challenging and rewarding intellectual pursuit, but there are also several practical reasons for studying plant function. These include contributions to the basic principles of crop management for optimum production and perhaps to a lesser degree to the development of crop germplasm. In crop management, plant physiology has contributed basic concepts in mineral nutrition, irrigation management, weed control, allelopathy, growth regulators, seed production and food technology. Plant physiology has contributed much less to the development of crop germplasm. Future inputs of plant physiological research into germplasm development probably will be made through the study of physiological ecology or environmental physiology.

Ecology is "the study of organisms in relation to their environment." It follows from this definition that *environmental physiology* is "the study of plant ecology through an understanding of plant function." The effects of various environmental parameters on physiological responses make up the heart of environmental physiology. One of the primary questions of environmental physiology is: "Why does a plant occur in a certain environment?" The answers to this question are: (1) by chance it happened to be there; (2) it can survive, grow and reproduce in that environment; or (3) it has not been eliminated by competition from other plants or animals. Environmental physiology is only concerned with the answer to how a plant survives, grows and reproduces. In developing new crop germplasm adapted to specific environments, the plant breeder depends on the environmental physiologist to provide this information for a specific plant and in terms he can understand and, more importantly, use.

PLANT GENETICS

Plant genetics, the scientific discipline of plant breeding, is "the study of the heredity mechanisms through which traits are passed from generation to generation" (Burns, 1969). Genetics is usually divided into the study of quantitative (differences among individuals that are of degree) and qualitative (differences among individuals that are of kind) traits. Virtually every organ and function of a plant have individual differences of a quantitative degree. Quantitative differences form a continuous series from one extreme to the other and do not fall naturally into sharply demarcated types. In contrast, qualitative differences separate individuals into distinct types with little or no connection by intermediate types. Examples of qualitative traits in cotton are red and green plant color, okra and normal leaf shape, etc. The mechanism of inheritance between quantitative and qualitative genetics is related to the number of genes that causes the observed differences. Quantitative differences, in so far as they are inherited, depend on gene differences at many locations on the chromosomes, the effects of which are not individually distinguishable (Falconer, 1960).

PHYSIOLOGICAL GENETICS

Most of the available literature shows clearly that the study of plant physiology and the study of plant genetics have proceeded largely independently of each other. The geneticist, preoccupied with the study of easily defined, mainly morphologic or agronomic traits, has tended to ignore possible genetic components of physiological traits. Reasons for this approach have been: (1) the greater difficulty in measuring physiological traits as compared with morphological ones; (2) the lack of available data supporting the importance of physiological traits; and (3) the lack of adequate training in plant physiology among plant geneticists. On the other hand, plant physiologists have given little attention to potential genetic components of physiology. Much of the physiology data assumes a relatively constant response for a crop species. This relatively constant genetic type is surveyed for a series of physiological responses so that the responses themselves are the variables under study (Ehrman and Parsons, 1976).

In both physiology and genetics, the organism of primary importance is the plant. Through measurement, the plant is given a value which is the phenotype. The phenotypic value results from the interaction of the plant's genes with its previous or present growth environment. In a mathematical sense, a plant's phenotype can be expressed as its genotype + the environment + the interaction of these two. An example of this type of interaction is shown in Figure 1. Verhalen and Murray (1970) showed the interaction of lint yield among several cotton (*Gossypium hirsutum* L.) cultivars and locations. The cultivars produced different yields depending on the location where they were grown. Through statistical

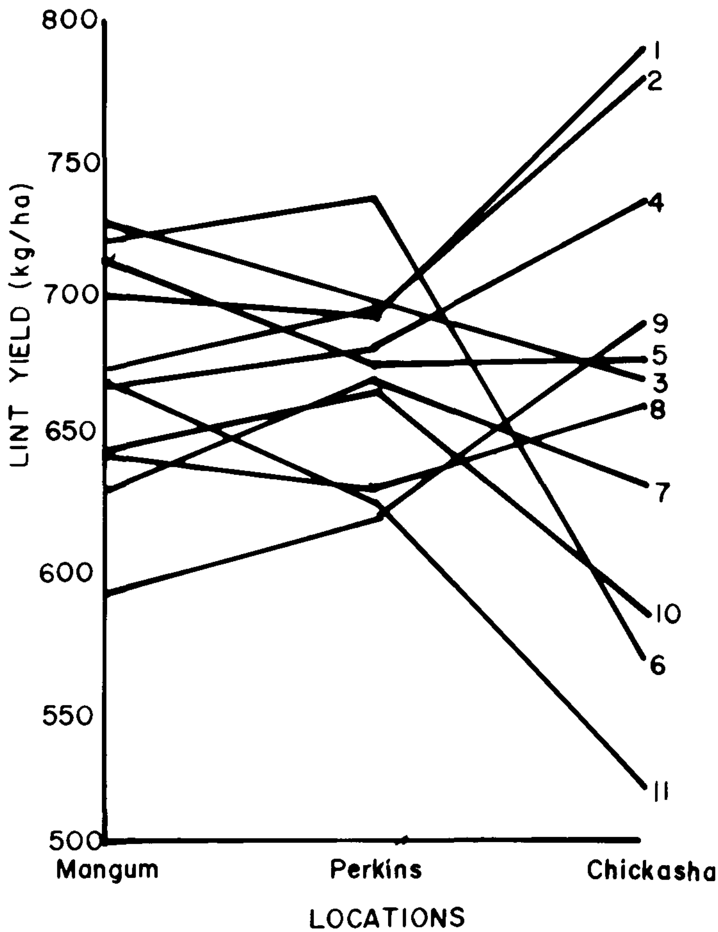

Figure 1. Genotype by environment interactions for lint yield of 11 cultivars at three locations in Oklahoma (from Verhalen and Murray, 1970).

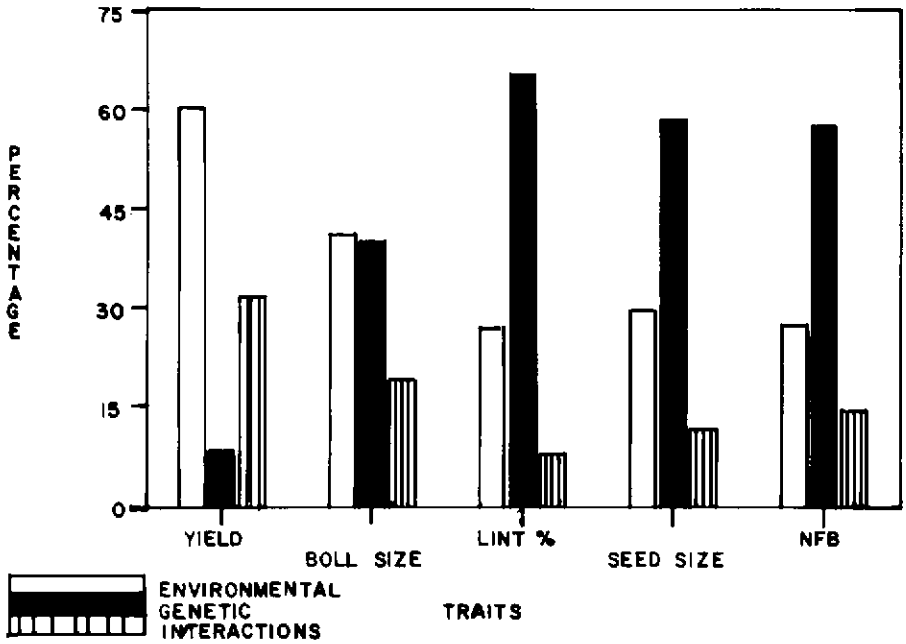

Figure 2. Partitioning of the phenotypic variance for five traits grown at three locations. Traits were lint yield, boll weight (size), lint percentage (%), seed weight (size) and node of first fruiting branch (NFB). Traits were measured in a two-year study at locations in Texas (from Quisenberry, unpublished).

partitioning, it is possible to calculate the percentage of the total variation contributed by the environment, genetics and the interaction of genetics with the environment (Figure 2). The data were taken from a two-year study of randomly selected cotton lines grown at three locations. Genetic variation was small for lint yield while much higher for the other four traits. This suggested that most of the variation observed in the population under study was caused by the environment and the interaction of the genetic and environmental components.

These data further suggested that yield improvement should come by making the best use of the environment. In fact, we know that the most productive research approaches to increase crop yields have been those directed to alleviate environmental barriers to crop production (reducing weed competition, optimizing available water and nutrients, improving soil conditions, etc.). This agronomic-oriented research has been the basis for most of the increases in crop yields in the past 100 years.

For the last 15 years, cotton yields have reached a plateau. I contend that this plateau has been a result of decreased environmental inputs related to their increased cost. For optimum cotton production in the future, an attempt must be made to maximize yield with continuous reductions in environmental inputs. This presents tremendous opportunities and challenges to those scientists involved in cotton research. Plant physiologists will be needed to define factors limiting plant development and growth. Defining these limiting factors will not be enough, they must also cooperate with the plant breeder to find biochemical, morphological or physiological methods to circumvent these factors. They must do this in the face of declining environmental inputs (water, insecticides, herbicides, fertilizer, etc.). Cotton cultivars must be developed that can make maximum use of these limiting environmental inputs.

How can a useful physiological trait be identified and used in a plant or breeding program? A diagrammatic representation of one approach is shown in Figure 3. The initial step is the generation of new ideas or concepts through basic or fundamental research. Since the ultimate use of this basic research is to develop improved crop cultivars, the research may require unique germplasm on which to explore basic concepts or ideas. Early in the research effort, the basic researcher needs to interface closely with a plant breeder. The basic research can

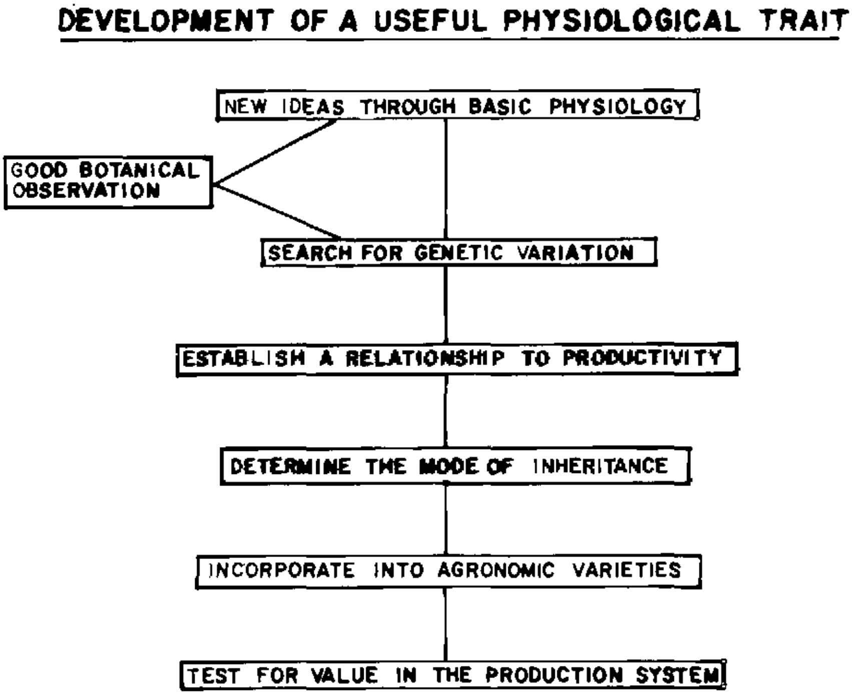

Figure 3. An approach toward using physiological traits and responses for genetic improvement.

be aided by the expert botanical observations made by plant breeders. Since plant breeding consists of qualified observations coupled with statistical quantification, observation is a key part of a successful plant breeding program. Most of a plant breeder's time is spent observing plant growth and development and trying to identify obviously superior plant-types. If the basic scientist can communicate to the plant breeder the type of mechanisms or strategies expected from a predicted physiological response, the probability is great that the plant breeder has observed such a response in some of his breeding material. Observation is a strong scientific tool.

As new concepts and ideas are generated, a search of available germplasm is needed to identify germplasm that encompasses the genetic concept or idea. As the research progresses to this point, it is no longer the primary responsibility of the plant physiologist but is passed on to the plant geneticist. The geneticist still needs the assistance of the plant physiologist in developing suitable methods to measure a large number of plants for the identified trait. These methods may require significant changes in techniques from those used in the original research. Often, the time consuming, exacting techniques used to develop basic concepts are modified through the development of new equipment or through the correlative identification of responses related to the original concept.

After a desirable trait is identified and a suitable technique to measure the trait developed, the geneticist will evaluate the available germplasm for genetic variability. The initial evaluations should be conducted on available cultivars. If useful variability can be found among these, the time required to incorporate the trait into new cultivars will be greatly reduced. If significant variability is not found among cultivars, then the search for variability will be expanded to include primitive germplasm, closely related species, and in some cases, closely related genera. The use of these more exotic sources of germplasm will increase the plant breeding problems.

When useable variability in a trait is found, the relationship between the trait and productivity and other quality traits should be determined. The determination of these relationships is some of the most difficult research to conduct. A correlative response among random lines from a population constructed by crossing genotypes with extreme expression of the trait is a useful approach. A positive correlation between the trait and productivity is suggestive but does not prove a cause-and-effect relationship. The comparison of isoline with and without the trait is better, but great difficulty exists in developing isolines, especially for quantitatively inherited traits.

As the plant breeder uses a physiological trait, he should have some information about how the trait is inherited. A comparison of the mode of inheritance between the new trait and other traits such as crop yield or quality will help to determine the plant breeding approaches that should be most productive.

The final two steps consist of: (1) incorporating the new response or trait into agronomic cultivars and (2) the evaluation of these cultivars in conventional production systems. A cultivar that has the new physiological trait may not be adapted to conventional production systems and, therefore, may require additional research to develop a production system where the trait can best confer its inherent advantages.

SUMMARY

The interface between physiology and genetics involves the desire of both disciplines to cooperate in mutually advantageous research. Difficulty exists in exchanging and understanding the technical terminology related to each discipline. All research should be oriented towards a "user" and the ultimate desire of the researcher to apply the research results. Application of research results requires that scientists communicate their findings in clear, precise terms that can be understood by scientists trained in other disciplines. The potential of applying basic physiological research to develop new cotton cultivars is an application worthy of the efforts.