Acknowledgment

The author thanks his colleagues who carried out this work, and especially K. Selby, who was responsible for it.

Literature Cited

(1) Clibbens, D. A., Geake, A., Ridge, B. P., *J. Textile Inst.* **18,** T277 (1927).
(2) Clibbens, D. A., Ridge, B. P., *Ibid.*, **19,** T398 (1928).
(3) Ellzey, S. E., Wade, C. P., Mack, C. H., *Textile Res. J.* **32,** 1029 (1962).
(4) Fargher, R. G., *Biochem. Soc. Symp.* (Cambridge, Engl.) **11,** 71 (1953).
(5) Gascoigne, J. A., Gascoigne, M. M., "Biological Degradation of Cellulose," p. 168, Butterworth and Co., Ltd., London, 1960.
(6) Petterson, G., Cowling, E. B., Porath, J., *Biochim. Biophys. Acta* **67,** 1 (1963).
(7) Preston, R. D., *Polymer* **3,** 511 (1962).
(8) Reese, E. T., in "Marine Boring and Fouling Organisms," p. 265, D. L. Ray, ed., University of Washington Press, Seattle, Wash., 1959.
(9) Searle, G. O., *J. Textile Inst.* **20,** T162 (1929).
(10) Selby, K., *Biochem. J.* **79,** 562 (1961).
(11) Selby, K., Maitland, C. C., *Ibid.*, **94,** 578 (1965).
(12) Selby, K., Maitland, C. C., Thompson, K. V. A., *Ibid.*, **88,** 288 (1963).
(13) Siu, R. G. H., "Microbial Decomposition of Cellulose," p. 267, Reinhold, New York, 1951.
(14) Van Haga, P. R., *Nature* **182,** 1232 (1958).
(15) Walseth, C. S., *Tappi* **35,** 233 (1952).
(16) Whitaker, D. R., *Can. J. Biochem. Physiol.* **35,** 733 (1957).

Received for review October 20, 1964. Accepted July 12, 1965. Presented before the Division of Agricultural and Food Chemistry, Symposium on World-Wide Research Program in Agricultural Chemistry, 148th Meeting, ACS, Chicago, Ill., September 1964. This research was conducted under a project authorized by U. S. Public Law No. 480, 83rd Congress.

WORLD-WIDE RESEARCH

Role of the Universities in Agricultural Research

JAMES BONNER

Division of Biology, California Institute of Technology, Pasadena. Calif.

The universities' essential role in agriculture, as in all fields, is the generation of new knowledge. The training of research workers is an integral part of the universities' work, since the student learns to make new knowledge by practicing doing so in apprenticeship to those who already possess the skill. The work of the universities has resulted in a knowledge explosion in biology, and we are now rapidly approaching both understanding and mastery of the processes of cell and organismal life. This new knowledge has as yet had no impact on agriculture. It is time for those of us interested in agriculture to try to foresee ways in which this impact may make itself felt.

The role of the university is to make new knowledge. This has been its traditional role since the founding of universities some 700 years ago. In those far-off years, to be sure, the universities made new knowledge only in the field of theology, but gradually they have accepted their responsibilities, spread their interests, and today their knowledge-making role extends through all fields of human interest and activity, from the arts to the exploration of the moon, from the wiring diagram of the brain to basic agriculture. We are here concerned only with agriculture, which is one facet of biology. For the agriculture-related aspects of biology, as for all biology, it is in the universities that our present knowledge explosion not only commenced, but is at present being carried forward. Let us not review past accomplishments in detail—let us merely consider a few, and then go on to the present state of biology. We will then determine what we can forecast for the future of biology and of agriculture.

From the universities have come in steady succession such new insights as our knowledge of the plant hormones, and hence of herbicides and the chemical control of senescence, the unfolding of the path of carbon in photosynthesis and our present close approach to an understanding of how light energy is converted to chemical energy in chloroplasts. This latter knowledge will one day make possible not only synthetic photosynthesis but also perhaps plant photosynthesis of improved efficiency.

The New Biology

From the university has come, too, the spectacular development of our modern insight into the nature of life. This development has all taken place within the past ten years. Its impact has not yet been felt in agriculture, nor do we know exactly the ways in which this impact will make itself felt. That its effects will be vast, we can have no doubt. Our new knowledge of life is truly revolutionary, for we know in detail what it is that makes the cell be alive. We know that all cells contain the directions for cell life written in the DNA of their chromosomes, and that these directions include specifications of how to make the many kinds of protein enzyme molecules, by means of which the cell converts available building blocks into substances suitable for making more cells. We know that to make enzyme molecules the DNA prints off RNA copies of itself, messenger RNA molecules, and that these messenger RNA molecules are decoded by ribosomes, also made by the DNA, and that the ribosome as it decodes the messenger RNA molecule uses the information to assemble a specific kind of enzyme molecule. We know that the information contained in DNA, and hence in messenger RNA, is encoded in these molecules in a sequence in which the four different kinds of monomers of which nucleic acids are constituted. succeed one another down the long linear polymeric chains of the nucleic acids, and that the sequence in which the nucleotides of the nucleic acids succeed one another in turn determines the sequence in which the 20 different kinds of amino acids are stapled together to make enzyme molecules. We know that it is by the sequence of the 20 different kinds of amino acids of which enzyme molecules are made that the nature of the particular enzyme molecule is determined. We know a great deal today about the determination of exact amino acid sequence in enzyme molecules. To a considerable extent we know how to make synthetically enzyme molecules of specified sequence. We know, too, a great deal about nucleotide sequence—we are beginning to learn to read the genetic language. It will soon be possible to synthesize a DNA molecule or a messenger RNA molecule of any specified sequence and hence of information content.

Nature of Developmental Processes

The picture of life given to us by molecular biology and sketched above is general—it applies to all cells of all creatures. It is a description of the manner in which all cells are similar. All cells possess DNA and this DNA makes messenger RNA, ribosomes, and hence enzymes. But higher creatures such as people, or pea plants, possess different kinds of cells. Some cells make hemoglobin, other cells do not. Some cells make pea seed globulin, others do not. The new biology is beginning to tell us why different cells in the same body are different from one another, and how such differences arise. Every cell in the body of a higher organism has exactly the same amount and kind of DNA, the same genetic information. A single cell, the fertilized egg, divides into two cells, and each of these receives a complete set of the genetic DNA. The daughter cells divide and divide, each cell continuing to receive a complete copy of the genetic book, but, in the course of embryonic development, the cells of the embryo soon begin to become different from one another. Some produce hemoglobin, some produce myscle enzymes, some liver enzymes, and so on. The genetic information for making hemoglobin, for example, is in all cells, but is used only in a few—those which are to be red blood cells. In the other cells of the body, the genetic information for making hemoglobin is turned off, repressed.

Control of Genetic Activity

To find out what causes development and differentiation, we must then find out what it is in the cell that determines that particular parts of the genetic information, particular genes, are active in particular cells and make their characteristic RNA's, and what it is that determines that other genes shall be repressed, inactive, in RNA making. The new biology is beginning to give us insight into these matters. It is now possible to isolate chromosomes intact from the cell, and to cause them to make messenger RNA in the test tube. It is possible to couple this messenger RNA production to ribosomes, so that enzyme molecules are made in the test tube. In this way, it is possible to show that chromosomes from different kinds of specialized cells make different kinds of messenger RNA, and hence different kinds of enzymes, kinds characteristic of of the cells from which the chromosome was isolated. In this way it is possible to show that the control of genetic activity characteristic of the chromosome in life is preserved in the isolated chromosome. It is, therefore, possible to study on an experimental level the control and programming of genetic activity, to study and find out about the material basis of development and differentiation. By this means, it has been possible to determine that the repressors, which make genes be inactive and incapable of making their messenger RNA, are proteins of a particular class, the histones. These are basic proteins which are bound to DNA in the structure of the chromosome. It has been possible to show, too, that derepression, the turning on of the gene, consists in the removal of the repressor protein. When we derepress genes in the laboratory by the removal of histone, we do so by dissociating repressor from DNA by the use of high concentrations of salt. It works nicely, but not selectively. It derepresses all repressed genes. In the living cell, derepression is selective; one or a few genes may be turned on or off without influencing others. The new biology is beginning to find out something about the nature of this genetic switching unit, the switching unit so basic to the entire process of development and differentiation. Particular kinds of small molecules are able to interact with repressor molecules in such a way as to turn off or on the activity of particular genes. One important class of small molecules which conducts this kind of regulation in higher plants and animals is the hormones. A hormone, on arrival at its target organ, turns on individual or whole sets of genes causing the production of characteristic enzyme molecules and setting a cell or cells on new pathways of development. This is true of both plant and animal hormones, and it would appear probable that interaction with the genetic material and with the consequent turning off or on of the genetic activity is the basic function of all hormones. Soon it will be possible to map out in detail the entire switching sequence by which, through the proper orderly and sequential programming of genetic activity, a single cell turned into a particular tissue, organ, or individual.

Immediate Future of Molecular Biology

Thus, biology approaches rapidly the point at which it will be possible to specify the DNA sequence needed to produce a desired character, to give that particular kind of DNA to a cell, and to cause the information to be acted upon. It is already possible to recombine genes in the test tube, and then to inject the recombinant genome into bacterial cells. Soon such mechanical reshuffling of the genome will be possible on all levels. We approach the time, too, when we can deliberately reset the developmental program, cause mature body cells to think that they are fertilized eggs, and to grow into embryos. This is, as a matter of fact, already true with higher plants. By this means alone it will be possible to produce rapidly any desired quantity of identical individuals. We may expect, too, to soon be able to reset the program to any point and thus to grow new organs, to eliminate undesired organs, to create any desired multiplicity of organs—such as four hands for busy biologists.

Our understanding of the way in which differences between cells is attained in life is leading biologists to some insight into the way in which facts are encoded in human memory. We may look forward to a real understanding of the logic and chemistry of brain function.

We are, then, today in the middle of what is for mankind the greatest revolution of all time. Just as some two million years ago our predecessors cleverly acquired the notion of using tools which made it then possible for them to develop into man, so today we are discovering the material nature of life, and will ultimately be able to direct it at will. It is a sobering thought.

Impact of the New Biology on Agriculture

What impact will our knowlege have on agriculture? One important impact of the new knowledge is already clear. The development of biggest impact on agriculture will in the long run surely be the antifertility pill and related developments. The control of human fertility provides hope that some day we may achieve a stable world population, and achieve this we must. We can then hope to bring the standard of living of all of the world's peoples up to a reasonable and hopeful level. A time will come, then, when the world's agriculture need no longer be so completely concerned as it is today with expansion. But the control of fertility is but one impact of biology upon agriculture. We should think about how to use our new knowledge of biology. The Agricultural Research Service is to be congratulated upon its wisdom in having set up in the Pioneering Research Centers, laboratories which will not only make new knowledge, but which will also consider how the new lore of biology is relevant to agriculture.

Education and Research—Partners in the University

We have spoken of the university as the place for the generation of new knowledge, and have minimized its educational function. The two functions are truly inseparable. The university is an institution in which circumstances are arranged so that young people learn how to make new knowledge by working in apprenticeship with creative investigators who already know how to do so. Education is almost a by-product of the university. The university, in our society, is the self-renewing center for the creative solution of mankind's problems.

Received for review October 20, 1964. Accepted July 9, 1965. Division of Agricultural and Food Chemistry, 148th Meeting, ACS, Chicago, Ill., September 1964. Work in the field of plant biochemistry supported by the Herman Frasch Foundation.

WORLD-WIDE RESEARCH

Role of State Agricultural Experiment Stations in Agricultural Chemical Research

MARK T. BUCHANAN
Washington State University, Pullman, Wash.

Experience shows that state experiment stations have the technical competence and facilities to contribute significantly to chemical and utilization research. The stations, USDA, and private laboratories sometimes use similar approaches. However, professional intercourse, literature review, cooperative planning, and listings with the Science Information Exchange keep the programs complementary rather than competitive. The most nearly unique features of experiment stations' activities include emphasis on basic research at numerous dispersed locations, regional research, cooperation among chemists and scientists in other disciplines in the same university, and the combined teaching and research function.

STATE AGRICULTURAL EXPERIMENT STATIONS, as part of the land-grant university system, are responsible for agricultural research, much of which involves chemistry. Most agricultural scientists are a specialized form of biologist, physical scientist, or social scientist, and even agricultural economists use chemical research results—e.g., when determining the most efficient feed or fertilizer alternative.

Owing to the current interest in research directed to discovery of new and improved food, feed, and industrial uses for agricultural commodities, and to the importance of chemical research in this program, this discussion will be limited to those phases in which chemical research may be related to improving the utilization of agricultural products. Such research is in progress at all 53 stations.

Station chemical research plays a key role in facilitating understanding of the basic properties of agricultural products, in developing new products, and in improving present products. This program, while designed to serve agriculture, serves the total economy by supplying industrialists with new opportunities for investment and with trained personnel, labor with additional employment, farmers with new sources of revenue, and consumers with new and better products. Much of the current work is quite fundamental. As a by-product, additions to the storehouse of knowledge of basic chemical and biochemical phenomena accrue to the benefit of current and future generations. The research program is documented with the Science Information Exchange.

Scope of Program

About $12.3 million are expended on utilization research by the state agricultural experiment stations. This amount represents about 7% of the total funds expended in support of their agricultural research programs.

Additional information on the scope of the station's utilization and utilization-related research program is in Table I. Table I reveals that in 1964 a total of 471.6 professional man-years of research time was devoted to utilization research on the various commodities. The distribution of research effort among commodity groups provides further insight into the nature of the program and the relative emphasis given various phases. For example, the man-years devoted to research on fruits, vegetables, poultry, dairy, and animal products illustrates the major emphasis which is being given food uses investigations.

Comparisons of these data for fiscal 1964 with similar data for fiscal 1963 reveal an increase of 30.3 professional man-years for fiscal 1964. This increase in support for utilization research continues the trend of recent years and reflects the increasing attention being given this field of research.

Centers of competence exist in the many station agricultural chemistry and biochemistry departments and in more than 20 departments of food science and technology. An Institute for Utilization Research has been organized at the Indiana station to bring together an

Table I. Utilization Research Conducted at State Agricultural Experiment Stations, Fiscal Year 1964

Commodity Group	Professional Man-Years[a]
Cereal and forage crops	47.0
Cotton, wool and other fibers	13.7
Fruits and vegetables	133.0
Oilseeds	14.6
Poultry, dairy and animal products	185.4
New and special plants	38.1
Forestry	39.8
Total	471.6

[a] Professional man-year calculations based on $26,000 per professional man-year.