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AGRICULTURE AND MODERN SCIENCE[1]

I FEEL a special sense of appropriateness in speaking on such a subject as "Agriculture and Modern Science" at Yale University. Much work in agricultural science has been carried on in Connecticut from pioneer days down to the present, largely under the leadership of Yale professors and investigators.

The earliest scientific paper on agriculture by a resident of the English colonies was that of John Winthrop, Jr., first governor of Connecticut, on the "Description, Culture and Use of Maize," read before the Royal Society in 1663. The Rev. Jared Eliot, of Killingworth, Connecticut, in the next century, is believed to have been the first American to publish a book on agriculture. Eliot, by the way, was a chemist. In 1764 the London Society for the Encouragement of Arts awarded him a gold medal for his process of making iron and steel from black magnetic sand.

Modern scientific study of agriculture in America may be said to have begun with John P. Norton, who undertook his duties as first professor of agricultural chemistry at Yale in 1847. Professor Norton, after making a promising beginning, died at the early age of thirty. His plans were carried to fruition by his pupil, Samuel W. Johnson, who held the professorship of agricultural chemistry at Yale for forty years, from 1856 to 1896. Professor Johnson is recognized as the father of agricultural research in the United States. The work which he did in the fifties as chemist of the State Agricultural Society in the analysis of fertilizers "for the information and protection of farmers" and the exposure of frauds attracted wide attention. As early as 1854 he advocated the establishment in this country of agricultural experiment stations and wrote: "What agriculture most needs is the *establishment of its doctrines*. . . . If agriculturists would know, they must inquire. The knowledge they need belongs not to revelation but to science, and it must be sought as the philosopher seeks other scientific truth."

Due largely to Professor Johnson's efforts the agricultural experiment station idea first took shape in the Connecticut station, which began its career at

[1] Address of the secretary of agriculture, at Yale University, New Haven, Conn., March 28, 1927, at 8: 15 P. M., under the auspices of the American Institute of Chemists.

Wesleyan University, at Middletown, in 1875. Professor W. O. Atwater, a former student of Johnson's, was made director. Professor Atwater laid the foundation of American scientific studies in human and animal nutrition. The station was incorporated as a separate institution in 1877 and moved to New Haven. Professor Johnson became director, and offices and laboratory were supplied by the Sheffield Scientific School.

Professor Johnson's contributions to agricultural science were many and valuable. "How Crops grow" and "How Crops feed" are agricultural classics. His influence in bringing science to bear on all the varied phases of agriculture was far-reaching.

The success of the Connecticut Experiment Station led other states to follow. Dr. Johnson was active in developing a wider interest.

Another movement which had an important bearing on the development of agricultural research was the establishment of the bureau, now the Department of Agriculture, and the land grant college system by congressional acts in 1862.

The Department of Agriculture from the beginning was planned to be a national research agency. It has been gradually developed along these lines until now it is the most extensive research agency of the kind in the world, expending for fundamental research bearing on agriculture in its larger aspects more than ten million dollars a year and employing more than a thousand trained investigators and in addition a corps of more than four thousand who assist in the work directly or indirectly.

In the development of the land grant colleges the needs for research as well as education were evident from the first. Research data on which to build a more scientific agricultural education were largely lacking. The earlier years of the colleges were therefore not impressive from the standpoint of accomplishment.

In 1887, largely through the efforts of the colleges, the Hatch act was passed. This recognized the joint responsibility of the federal and state governments for promoting agricultural research and provided $15,000 a year to each state for that purpose. This was later increased under the Adams act to $30,000, and recently under the Purnell act to a final total of $90,000 a year to each state. On the average, not counting buildings, land and overhead of that kind, the states provide in addition two or three times as much more.

The general supervision of the work on the part of the federal government devolves upon the Department of Agriculture through a special Office of Experiment Stations, provided by law for that purpose. The closest cooperation has developed in practically every phase of the work.

The three acts mentioned have somewhat different objectives. The first, the Hatch act, was general in its terms. The Adams act was designed to develop more fundamental research. The Purnell act broadened the field to include economic, sociological and home economic studies. In the earlier years problems of production, control of disease and insect pests, introduction and development of improved varieties of crops and animals, studies of fertilizers and soil fertility, feeding and breeding of livestock were paramount objectives. To-day these are not less important, but problems of marketing, finance, transportation and other economic and social aspects of agriculture are dominant and require the same careful study and analysis that have been given to the production aspects.

There is also a difference in point of view between the earlier and the later work in agricultural research. In the early stages, agricultural science borrowed heavily from general science, the discoveries in which it endeavored mainly to apply to agricultural problems. Latterly, institutions for agricultural research have themselves become contributors to scientific discovery to a constantly increasing extent.

Examples of agricultural progress through research may be found in practically every science and every group of sciences.

In chemistry the classic example is the early work on fertilizers. The foundations of this branch of agricultural science were laid by such chemists as de Saussure (whose "Chemical Researches upon Vegetation" was published in 1804), Boussingault, who introduced exact field experiments with fertilizers in 1834, and especially Liebig, whose epoch-making book, "Chemistry in its Application to Agriculture and Physiology," was published in 1840. Liebig's book was the foundation of modern scientific agriculture. His work inspired J. B. Lawes in England, who first began the manufacture of calcium superphosphate as a fertilizer and founded the first agricultural experiment station at Rothamsted.

One of the most brilliant examples of the benefits which have been conferred by chemistry upon agriculture is the Babcock test for determining the butterfat content of milk. It won grand prizes at both the Paris and St. Louis Expositions. Babcock's invention, from the effect which it had in improving dairy herds, in securing the payment for milk and cream upon a fat percentage basis, in controlling the processes of manufacturing dairy products, and in regulating the purity of municipal milk supplies, has been of inestimable value to the American people, although he himself, by generously dedicating his process to the public, has had no share in the vast financial benefits which others have acquired.

The importance of fundamental research in chemistry to agriculture is illustrated by the researches of Professor Sabatier, of France, upon catalysis. Sabatier directed attention to the great importance of certain contact agents, such as finely divided metals, in promoting chemical reactions. One of the first industrial applications was in the hydrogenation of liquid vegetable oils for the production of solid fats. The use of this process upon the hardening of cottonseed oil for the production of new shortening agents has added millions to the value of the annual cotton crop of the United States. Another application of catalysis in industrial chemistry is the Haber process for the fixation of nitrogen, the nitrogen of the atmosphere and gaseous hydrogen being made to combine under pressure and in the presence of a catalyst to form ammonia. This ammonia can then be converted into ammonia salts or oxidized to nitric acid for the production of nitrates, both of which are of immense value to agriculture as fertilizers.

Chemistry has also been of great help to agriculture in assisting in the improvement of crops by chemical selection. The selection of mother beets of the highest sugar content for seed production is an example of such an application of chemistry. The sugar content of the beet has been more than doubled by this means. A simple rapid accurate method for the determination of sugar was made possible by the invention of the polariscope by the French scientist Biot in 1840. This instrument in its valuation of the sugar-producing crops of the world has been worth many millions of dollars annually to agriculture and the agricultural industries.

The feeding of farm animals is no longer conducted by the happy-go-lucky methods of fifty years ago, but is performed in accordance with the strictest application of the laws of physiological chemistry. The newer knowledge of the food value of proteins and vitamins, so much of which is due to the work of Drs. Osborne and Mendel, of Yale University, has been a development of the twentieth century. The accurate measurement of the energy-producing value of foods, when consumed by the human organism, was first made possible by the respiration calorimeter of Professors Atwater and Rosa at Middletown, Connecticut, in experiments which were sponsored and financed by the United States Department of Agriculture. A similar calorimeter for work upon farm animals was erected by Dr. H. P. Armsby at the Pennsylvania State College, and the results obtained with this instrument have done much towards placing the nutrition of farm animals upon the basis of an exact science.

One of the most important applications of science to agriculture of recent years is the discovery in the United States and England of methods for the direct conversion of waste straw into barnyard manure, a matter of importance to farmers who have straw but lack the animals for changing it into manure. In the process as developed at the Rothamsted Experiment Station, England, the straw is heaped up in stacks, treated with water and ammonium carbonate and then allowed to stand. Decomposition of the straw advances rapidly and a black product is obtained which resembles in appearance and properties barnyard manure.

The profitable utilization of agricultural waste products has engaged the attention of the United States Department of Agriculture since the time of its establishment sixty-five years ago.

An early example of what chemistry has done in the utilization of agricultural wastes is the working up of cottonseed into useful commercial products. Fifty years ago, when the industrial utilization of cottonseed was in its infancy, the disposition of the refuse seed which accumulated about the cotton gins was a most serious problem. In some cases the seed was thrown into streams, but the pollution of the river water, which was caused by this practice, led to the passage of laws, still in existence, attaching a penalty to this wasteful method of disposal. In other cases the seed was allowed to decay in large piles, which, because of the objectionable odors, became a nuisance. Chemists were, however, busily engaged in studying the potential wealth contained in this wasted material with the result that to-day the utilization of cottonseed for the production of fertilizers, cattle feeds, oil, soap and other products is the second largest manufacturing industry of the south. The seed which was formerly wasted is now converted into products which are worth many millions of dollars. But the end has not yet been reached, and the efforts of chemists are now being directed towards the study of methods for converting cottonseed meal into a valuable food for man. A serious obstacle in this direction is the presence in cottonseed of a toxic substance known as gossypol, which, when consumed in too large an amount in certain meals, has caused the death of farm animals. A study of this toxic substance and of the best methods for its removal is now being undertaken in a collaborative research by the Bureau of Chemistry, Department of Agriculture, and the Interstate Cottonseed Crushers' Association. There is every reason for believing that the valuable protein constituents of cottonseed before many years will be made into safe and palatable foods for human consumption.

I have devoted much time to the discussion of chemistry in relation to agriculture, as I feel it is a subject of special interest to the majority of my auditors. Highly significant work has been done in many other sciences and in groups of related sciences, however, and I wish to present to you briefly a few typical examples.

The introduction and improvement of plants have proved very important to agricultural progress. The United States Department of Agriculture has introduced more than 65,000 different plants procured by explorers in various foreign countries. For the last fifteen years the increased wheat production from the establishment of durum wheats, introduced from Russia by the late M. A. Carleton, has been more than 20,000,000 bushels annually. The introduction of grain sorghums, the development of improved and adapted varieties and the devising of suitable cropping methods have accomplished much in extending safe farming into the drier parts of the central and southern Great Plains. The citrus industry has been greatly benefited by bud selection for nursery propagation, based on tree-performance records.

Methods of growing cotton have been revolutionized in recent years by the new method of thick spacing of "single-stalk" plants, based on a technical botanical discovery by specialists of the Department of Agriculture that the cotton plant has two distinct kinds of branches. The single-stalk cotton is earlier and more productive, especially under boll-weevil conditions or in short seasons. The yields are often increased from 10 to 30 per cent., or even from 50 to 100 per cent., or more under some conditions, by the new method.

Identification and determination of the causes of destructive plant diseases and the development of methods for their control have done much to add safety to agricultural practice. This work is, obviously, based on fundamental research in plant pathology.

Research in the field of soils involves physics, chemistry, biology and soil classification. The aim of the physicist is to make the soil a more efficient medium physically for the growth of plants. The business of the chemist is to determine the chemical nature of soils and to insure that the plants grown in the physically efficient soils are supplied fully and cheaply with the nutrient elements required for the best growth. To the soil bacteriologist the farmer looks when he wants to be sure that his soil will grow a particular kind of legume, and to him the farmer has not looked in vain, for science has made it possible to inoculate soils by means of pure culture of nodule organisms. The investigators in pure soil science are engaged in identifying individual soils and in classifying and mapping them. In this field of endeavor the United States is far in the lead of other countries, owing to the untiring efforts of Dr. C. F. Marbut, chief of the Soil Survey. The Soil Survey is the only scientific institute which gathers facts about soils of the whole country and shows their relationships. It has taken numberless centuries for men to realize that individual soils exist, and that the first step toward understanding them is to classify them.

Enormous aid has been given to agriculture through minute research dealing with insects that prey upon crops or livestock. Among the lines undertaken in parasitology is the investigation of the life histories of parasites. Much attention has been devoted to this by the Department of Agriculture.

For example, the Texas fever tick was found to pass its entire life from the seed tick to the engorged adult on a single host animal, and hence it was found possible to eradicate ticks by dipping cattle alone—which would be a much less adequate procedure if the ticks passed parts of their life cycle on other host animals as many ticks do.

The sheep stomach worm was found to ascend grass blades in the presence of moisture. This discovery directed attention to the danger from wet pastures and short grass. The parasite was found to reach the egg-laying stage in the intestine in about three weeks, leading to a recognition of the necessity of moving sheep to clean areas or else treating them every three weeks to prevent reinfestation.

Valuable studies have likewise been made in the correlations between the chemical composition and water solubility of anthelmintics and the value of these drugs in removing worm parasites.

A consideration of the chemical composition of chloroform as indicating that its value against hookworms was due to its chlorine content led to the development of carbon tetrachloride, a related compound, as an anthelmintic for use against hookworms. Since 1921 this has been generally used in veterinary and human medicine. It has been found of value against many kinds of roundworms in animals and has recently been found to be effective in destroying liver flukes in sheep, being the cheapest of the effective preparations known for this purpose. Pursuing the same line of investigation resulted in the discovery that tetrachlorethylene, another related compound, is equally effective against hookworms and is apparently safer. Further studies are being carried on with a view to developing from a chemical basis a drug which will be of value in removing several sorts of worm parasites not at present susceptible to satisfactory treatment with any one drug. It has been ascertained in connection with these investigations that the water solubility is a factor of importance and that there is a point of optimum solubility which is approximately known at present.

The intimate structure of injurious insects, their physiology, their ecology and their various reactions are being minutely investigated.

These investigations have in many cases led to practical results. A very recent one relates to the Japanese beetle, an accidentally introduced pest which threatens great damage to American horticulture. Investigations of the olfactory sense of this species have led to the discovery of a chemical attractant that makes possible ready destruction of the adult beetles in great numbers.

Animal industry has profited greatly from the application of science to its problems. The importance of the vitamins and of light to the growth and development of animals is recognized by all. The significance of vitamin E, and possibly a vitamin which has an influence upon lactation has not so far been generally realized in applications to the industry.

The importance not only of the quantitative distribution of foodstuffs, but of the qualitative character of the constituents of an animal ration, has been discovered from investigations in both general and animal physiology in addition to direct studies of nutrition. Knowledge of the importance of an adequate supply of protein of a good qualitative character and of the nature of the deficiencies of certain proteins has been derived from reciprocal relations between studies in pure chemistry and in nutrition.

Our understanding of the gross nutritive requirements and the relation between the character of food and the production of work has been drawn from the fields of physics and physiology and applied through calorimetric studies on animals themselves. As the advances in animal nutrition are examined it is found that there always has been a close relation between studies in fundamental sciences, particularly those of chemistry, physiology and physics, and the final application of the principles developed to farm practices.

Destructive animal diseases have been brought under control by scientific means. Blackleg and hog cholera, for example, are now preventable at a merely nominal cost for vaccines.

The importance of meteorology to agriculture was early recognized here at Yale University, where Elias Loomis, who was professor of natural philosophy and astronomy from 1860 to 1889, became recognized as the foremost meteorologist of the United States.

As a result of research in this field, our climatology is now known, and it is possible to state where this or that crop can or can not be grown successfully. The relations of the yields of various crops to the prevailing weather conditions at their several stages of growth have been studied, and in many cases helpful estimates of yields can be made weeks and even months before harvest.

The duration and intensity of sunshine are of great importance to all varieties of vegetation, but very unequally so. Similarly the spectral quality of the light likewise is of great importance, not alone in vegetable growth but also to animal health. Studies of these relations are just beginning—a field of investigation that offers endless opportunities in pure science, and promises significant practical applications.

The applications of science to agriculture are important not only in production but in marketing—a field which is growing rapidly in significance to the farming of this country.

Pure science has a direct relation to the marketing of grain, notably wheat. The protein content of wheat has played an increasingly important part in the price paid for this grain at the large terminal markets during the past few years. The state of Minnesota maintains fully equipped chemical laboratories at Minneapolis and Duluth. Every car of wheat received at these markets is tested for the protein content and certificates covering the protein content of the wheat are issued by the state. The state of Kansas and the state of Missouri maintain a chemical laboratory at Kansas City for the same purpose. At other important terminal markets where wheat is received in large volume chemical laboratories are maintained by either the state or the local grain exchange. In addition many commercial chemists find a field for business in determining protein content of wheat.

This direct application of the pure science of chemistry to grain marketing is a comparatively new development. There is much room for it to expand still further. For example, the protein test now applied is for the purpose of determining the quantity of protein which the wheat contains. The quality of the protein is fully as important to the miller as the quantity. Up to date, however, no reliable, satisfactory method has been developed for determining the quality of protein in wheat. The development of such a test would probably revolutionize the system of buying and selling wheat in much the same way that the Babcock test revolutionized the dairy industry.

In considering the interrelationships of prices, marketings, supply, plantings, breedings and other questions, there is being developed a scientific approach in order to obtain quantitative answers. We are no longer satisfied, for instance, with the knowledge that bumper crops depress prices, or that low-priced feeds cause farmers to produce more livestock. We want to know the effect on price of a large crop (in dollars and cents), and the exact number of pounds or the number of head of meat animals which will be forthcoming as a result of given feed prices.

In working with these problems it has been necessary to devise new advanced statistical methods—an example of the application of mathematics to agriculture. The reason that economists have not heretofore been able to express their observation quantitatively is that they have not been able to determine the conditions under which they made their observations. Unlike the natural scientists, they have not been able to take their problems into a laboratory to observe facts undisturbed by varying outside conditions. If, for example, they attempted to study the effect of the size of the domestic wheat crop on price, they were confronted by numerous complicating factors, such as the production of other grain crops, the production of wheat in foreign countries, the changes in the general commodity price level, and the fluctuations in business conditions. Now, however, by the use of correlation methods recently developed, these general factors can be isolated and their separate influences on each other measured.

The examples which I have cited, from many sciences and from many agricultural enterprises to which the results of research have been applied, merely suggest the debt which modern agriculture owes to science. It is no exaggeration to say that through the research accomplishments of recent years the average farmer to-day knows more of the science on which his industry rests and brings it into constant application than the scientist knew fifty years ago.

Yet there remains much to be done. The agricultural field is full of problems, a large proportion of which depend for their solution on the effectiveness with which underlying problems in pure science are dealt. American science, I am convinced, needs to concern itself more with fundamental research than it has done heretofore. No country in the world has made such progress in applied science, but our record in pure science is not so flattering. Since 1900, when the Nobel prizes in physics, chemistry and medicine were inaugurated, seventy-six awards have been made. Of these, twenty-four went to Germany, eleven to England, ten to France, six to the Netherlands, five to Sweden, four to the United States, three to Denmark, three to Swtizerland, two each to Austria, Canada, Italy, and Russia, and one each to Belgium and Spain. On the basis of population, the Netherlands, Denmark, Sweden and Switzerland received one to every million inhabitants; Germany one to every two and one half million; Austria one to every three million; England one to every three and a quarter million; France one to every four million; the United States, one to every twenty-nine million.

This is the situation despite the fact that we have vastly more students in colleges and universities in proportion to the population than has any other country in the world. The difficulty seems to me twofold: We are not laying enough emphasis on pure science in proportion to our emphasis on the applications of science; and we are not stimulating and training an adequate personnel in scientific research.

Indeed, superior personnel is needed in every field touching scientific work. There is grave need, as I have pointed out, for workers in pure science. There is need likewise for those who can correlate and coordinate the facts discovered.

There is demand also for those who can interpret and apply to practical problems the results obtained through scientific investigation.

The agriculture of the future will be successful in proportion to the extent to which it is shaped and guided by the basic facts revealed by scientific research, especially research in the fields of natural science, economics, engineering and business administration. If satisfactory progress is to be made in the solution of the diverse problems of the farm, to the end that agriculture may be more prosperous, the facts developed by research must be intelligently correlated and coordinated, superficials distinguished from fundamentals and the latter interpreted in the light of practical knowledge as well as scientific information.

Of supreme importance is a sufficiently numerous personnel characterized by outstanding ability, thorough professional training and unstinted devotion to the search for the truth. To the development and encouragement of such a personnel every organization concerned with science may wisely lend its hearty efforts.

W. M. Jardine

RESEARCH IN COLLEGES AND PROFESSIONAL SCHOOLS. II

A REPORT OF SUGGESTIONS FROM THREE CONFERENCES

I should like to bring to you some of my own thoughts as to the importance of encouraging research in colleges and professional schools and the results that should follow. I am frankly optimistic as to these results if—I should like to discuss the results and the if. But it seems more appropriate, instead, to review some of the suggestions that have come from conferences and a number of consultations with leaders in research and in college work.

Among university graduates who enter upon college teaching the research death-rate is too high. Its being so high is a disadvantage (a) to the men them-