CHAPTER XI

AGRICULTURAL CHEMISTRY

BY CHARLES A. BROWNE

The Early Workers

Chemistry and agriculture have maintained a close relationship in America from the very beginning. The earliest chemist of the English Colonies, John Winthrop, Jr., first Governor of Connecticut, was greatly interested in agriculture and in 1663 read a paper upon the "Description, Culture and Use of Maize" before the Royal Society, of which he was a member. From the date of this early contribution the records of agricultural chemistry in America are almost continuous.

The importance of chemistry to agriculture was clearly realized by the founders of our Republic. Thomas Jefferson, during his presidency, and John Adams, during his retirement upon a farm at Quincy, recommended in almost identical words the pursuit of chemistry in so far as it helped to produce better bread, butter, cheese, beer, wine, cider, gardens, orchards, and fields, but they both expressed themselves as unfavorable to the study of chemical theories. This stress upon the practically useful appears also in many American textbooks of the early nineteenth century which dwell constantly upon the parts of chemistry of most utility to farmers, mechanics, and housewives. But notwithstanding some excellent features in the works of Thomas Ewell, Amos Eaton, Edmund Ruffin, Samuel Dana, and other writers of this period, agricultural chemistry in America, as in other parts of the world, wandered aimlessly about until 1840 when it was set definitely upon the right path with the publication of Liebig's "Chemistry in Its Applications to Agriculture and Physiology."

EBEN N. HORSFORD.—The earliest of Liebig's American students to promulgate his master's teachings was Eben N. Horsford (1818–1893), who published in 1846 his "Chemical Essays Re-

lating to Agriculture." In 1847 he became Rumford professor of chemistry at Harvard and exerted a great influence upon chemistry in America during the next forty years. He was greatly interested in the chemistry of foods, as is shown by his "Theory and Art of Breadmaking," published in 1861, and by his technical processes for manufacturing baking powder and condensed milk. He was one of the chemists who attended the Priestley Centennial at Northumberland in 1874 and later he became a member of the AMERICAN CHEMICAL SOCIETY. His diversified activities as teacher, manufacturer, and antiquarian brought Professor Horsford a greater degree of popular celebrity than was achieved by any American chemist of his day.

ST. JULIEN RAVENEL.—Members of the medical profession have always played a conspicuous part in agricultural chemistry in America, and prominent among these should be mentioned St. Julien Ravenel (1819–1882), of Charleston, South Carolina, the descendant of French Huguenot pioneers. He graduated from the Medical College of South Carolina in 1840 and, after completing his studies in Philadelphia and Paris, returned to Charleston to take up the practice of medicine. In 1852 he retired from medical practice in order to devote his attention to the applications of chemistry to agriculture. He visited the marl bluffs on Cooper River in 1856 and, ascertaining that this rock could be converted into lime, established kilns which furnished most of the lime used in the Confederate States. During the Civil War Dr. Ravenel was surgeon-in-chief of the Confederate hospital in Columbia and director of the Confederate laboratory in that city for the manufacture of medical supplies. He was the first to realize the immense agricultural importance of the phosphate rocks of South Carolina, and his experiments upon the transformation of these deposits into commercial fertilizers marked the dawn of the mineral phosphate industry of the South. He founded the Wando Phosphate Company for the manufacture of fertilizers and conducted extensive field tests upon the application of fertilizers to crops. He also made an agricultural chemical survey of the rich alluvial rice lands of his native state. Dr. Ravenel was especially distinguished for his philanthropic services in various outbreaks of yellow fever and his name is still revered in many places that were visited by this epidemic. The following tribute was paid to him in 1882, at the time of his death, by Charles Upham Shepard, Jr.:

> Well might this community erect a public monument in honor of the man to whom preëminently is due the inauguration of that phosphate industry

which has proven of such incalculable value to ourselves and others. As the statue of Berzelius adorns beautiful Stockholm, let us commemorate the founder of Charleston's greatest industry.

JOHN P. NORTON.—Two brilliant young scientists, John P. Norton (1822–1852) and Evan Pugh (1828–1864), upon returning from their European studies, gave a great impetus to the study of agricultural chemistry in America. In 1847 Norton was appointed professor of agriculture at the Yale Scientific School and during this connection published in 1850 his "Elements of Scientific Agriculture," which was awarded a prize by the New York State Agricultural Society. Until his early death at thirty Norton distinguished himself as a copious writer upon agricultural subjects and as an inspiring teacher.

EVAN PUGH.—Dr. Pugh is best known for his famous research upon the "Sources of the Nitrogen of Vegetables," which was conducted during 1857–1859 in the laboratory of Lawes and Gilbert at the Rothamsted Agricultural Experiment Station in England. He returned to the United States in 1859 to accept the presidency of the Pennsylvania Agricultural College and died in this office five years later at the age of thirty-six. In the early deaths of two such investigators as Norton and Pugh, American agricultural chemistry suffered a most serious loss.

SAMUEL W. JOHNSON.—The most potent influence in early American agricultural chemistry was Samuel W. Johnson (1830–1909), third President of the AMERICAN CHEMICAL SOCIETY, whose youthful essay in 1847 upon "Fixing Ammonia" gave promise of the man. He was inspired to make agricultural chemistry his life work by his teacher, J. P. Norton, at Yale during 1850 and 1851. After returning from his European studies under Liebig, young Johnson was appointed professor of analytical chemistry at the Yale Scientific School in 1856. The subject of agricultural chemistry was added to his professorship in 1857 and this became the central activity of his career during the next fifty years. Seven books and one hundred and seventy-two articles upon agriculture and agricultural chemistry are among the evidences of his industry. His lectures and publications upon soils, rotation of crops, fertilizers, methods of analysis, plant nutrition, food adulteration, and many other subjects exerted a great influence upon the development of scientific agriculture in America. By beginning in 1856 a systematic chemical examination of the commercial fertilizers which were sold in Connecticut, Johnson became the founder of agricultural regulatory work in America. He was largely instrumental in securing the passage of the Connecticut law of 1869 which, although imperfect, was

the first that required fertilizers to be labeled with a statement of composition, thus helping to fulfil the prophecy of his teacher, Liebig, that the time would come when no artificial manure would be sold whose exact amount of efficacious ingredients was not known.

A most important event in the history of agricultural chemistry in America during the past fifty years was the establishment of the State Agricultural Experiment Stations, and in the early stages of this movement Johnson was the undisputed leader. For many years he had advocated the establishment of a State Agricultural Experiment Station, but it was not until 1875 that Connecticut made its first attempt with private financial support to found an institution of this kind at Middletown with W. O. Atwater (1844–1907), a former pupil and assistant of Johnson, as director. Two years later Connecticut reorganized its experiment station as a wholly independent state institution in New Haven with Johnson as director. The Connecticut Agricultural Experiment Station, of which the fiftieth anniversary was celebrated on October 12, 1925, was instrumental in training many chemists who afterwards became directors of experiment stations in other states, when their establishment was made possible by federal support under the Hatch Act of 1887. H. P. Armsby, director of the Pennsylvania station; E. H. Jenkins, director of the Connecticut station; W. H. Jordan, director of the Maine and later of the New York station at Geneva; A. T. Neale, director of the Delaware station; and C. D. Woods, director of the Maine station, all obtained their early agricultural chemical training in Connecticut, either at Middletown or New Haven.

Johnson was an excellent critic of agricultural chemical work and, while himself making no contributions of striking originality, he performed a lasting service in the two classic volumes, "How Crops Feed" and "How Crops Grow," by winnowing the essential truths of the science from the chaff which had accumulated from preceding generations. These works have been translated into many foreign languages. Professor Johnson is also to be remembered for his well-known translations of the famous manuals of Fresenius by which many American chemists obtained their introduction to qualitative and quantitative analysis.

CHARLES A. GOESSMANN.—Next to S. W. Johnson the leading influence in American agricultural chemistry fifty years ago was Charles A. Goessmann (1827–1910), President of the AMERICAN CHEMICAL SOCIETY in 1887. The interests and activities of these two men ran parallel in many ways. Goessmann was born at

Fritzlar, Germany, and after taking his doctor's degree at Göttingen in 1852, served five years as assistant at this university under his teacher, Friedrich Wöhler. The publication in 1854 of a paper upon his newly discovered arachidic acid attracted immediate attention. Numerous contributions upon the composition of vegetable oils and other plant constituents followed in rapid succession.

Among those whom Goessmann taught at Göttingen were the American students G. C. Caldwell, C. F. Chandler, W. S. Clark, John Dean, E. P. Eastwick, J. H. Eastwick, S. S. Garrigues, J. D. Hague, Edward Hungerford, C. A. Joy, J. F. Magee, J. W. Mallet, Ebenezer Marsh, H. P. Nason, Evan Pugh, D. K. Tuttle, and G. W. Weyman. Including Goessmann himself there were in this group five future Presidents and five Charter Members of the AMERICAN CHEMICAL SOCIETY.

In 1857 Goessmann was persuaded by his former students, the Eastwick brothers, to become the chemist and superintendent of their sugar refinery in Philadelphia. After eleven years of technical activity in the United States with sugar and salt industries Goessmann accepted in 1868 the professorship of chemistry at the Massachusetts Agricultural College at Amherst. In 1882 he was also appointed director and chemist of the newly established Massachusetts Agricultural Experiment Station. Until his retirement in 1907 Goessmann published three hundred and sixty-two chemical papers and reports. His contributions upon soils, fertilizers, tillage, sugar cane, sugar beets, sorghum, fruits, ensilage, cattle feeding, dairy products, etc., cover the whole range of the applications of chemistry to agriculture, and his researches gave a strong impress to the character of the work which many American agricultural experiment stations took up in the early years following their establishment. Largely as a result of Goessmann's activities, the Legislature of Massachusetts passed the first effective state laws for controlling the purity of fertilizers and feeding stuffs.

Goessmann, like Johnson, exerted a great influence, through his pupils, upon the future of agricultural research in America. He foresaw the importance of the agricultural chemical investigations of Henneberg, Tollens, and others of the Göttingen school and he encouraged not only his own graduates but others to complete their scientific training at this university. The drift of young American chemists to the Agricultural Institute of Göttingen continued unslackened until the World War; E. W. Allen, C. A. Browne, W. B. Ellett, E. R. Flint, J. B. Lindsay, T. L. Lyon,

B. B. Ross, H. E. Stockbridge, W. E. Stone, Charles Wellington, H. J. Wheeler, J. A. Widtsoe, F. W. Woll, P. A. Yoder, and many others participated in this movement.

ROBERT C. KEDZIE.—Another early pioneer in American agricultural chemistry was Robert C. Kedzie (1823–1902). After graduating from Oberlin College in 1846 and from the Michigan State University Medical School in 1851 he practiced medicine until 1861. He then entered the Army to serve as surgeon in the Civil War, but resigned in 1863 to accept the professorship of chemistry at the Michigan Agricultural College where he taught until his death. In addition to his long services as a teacher of agricultural chemistry, Dr. Kedzie did a large amount of practical experimental work that was of great value to the farmers of his state. He studied the muck lands and other soils of Michigan, investigated the importance of the volatile constituents of animal manures to crop growth, and made experiments upon the fertilizing action of wood ashes, lime, land plaster, and salt. The Michigan fertilizer law was largely the result of his labors, as were also various other enactments for protecting the public welfare. His crusades against adulteration and other frauds were conducted with persistence and vigor. His investigations upon the chemical composition and baking quality of Clawson wheat were of great value to Michigan farmers. He was the first to grow sugar beets in Michigan and the Michigan beet sugar industry owes its origin to him. Dr. Kedzie was one of the group of chemists who attended the Priestley Centennial at Northumberland in 1874. He took an active part in the work of the Association of Official Agricultural Chemists, and was president of that organization in 1899.

NATHANIEL T. LUPTON.—Nathaniel T. Lupton (1830–1893) should also be mentioned as one of the more prominent early agricultural chemists of America. He was born at Winchester, Virginia, and obtained his collegiate training at Dickinson College, Pennsylvania, where he received the M.A. degree in 1849. After teaching for a number of years he took a postgraduate course in chemistry under Bunsen at Heidelberg. During the Civil War he was chemist in the Ordnance Department of the Confederate Government at Selma, Alabama, where he supervised the manufacture of powder. After the war he became professor of chemistry at the University of Alabama, of which he was president from 1871 to 1874. From 1875 to 1885 he was professor of chemistry at Vanderbilt University. In 1885 he was appointed professor of chemistry at the Alabama Polytechnic Institute and state

chemist of Alabama, retaining these positions until his death. He published his "Elementary Principles of Scientific Agriculture" in 1880 and was president of the Association of Official Agricultural Chemists in 1892.

FRANCIS H. STORER.—Two other chemists of the older generation, who exerted a great influence upon the development of agricultural chemistry in America, were F. H. Storer (1832–1914) and E. W. Hilgard (1833–1916). Their work, although of very different character and in widely separated states, was closely contemporaneous. Storer obtained his first training in chemistry at Harvard, where he graduated in 1855. After returning from two years' postgraduate study in France and Germany he occupied various positions as consulting chemist and teacher until 1870, when he was appointed professor of agricultural chemistry at Harvard. In the following year Storer was made dean of the Bussey Institution of Harvard and he retained these two offices during the rest of his active career. He published numerous papers upon fertilizers, fodders, foods, wood, and other agricultural chemical subjects. Professor Storer is best known for his three-volume treatise, "Agriculture in Some of Its Relations with Chemistry." He also published "First Outlines of a Dictionary of Solubilities of Chemical Substances" and a "Cyclopedia of Quantitative Chemical Analysis."

EUGENE W. HILGARD.—E. W. Hilgard was born in Bavaria and came to the United States with his parents when only three years of age. After attending the public schools of southern Illinois he studied abroad at Zürich, Freiberg, and Heidelberg, receiving the degree of Ph.D. at the last-named university in 1853. In 1855 he became chemist of the Smithsonian Institution but soon resigned this office to conduct geological studies in Mississippi, where he was state geologist from 1858 to 1872. It was during this period that he began his epoch-making investigations upon the chemical composition and geological formation of soils. Hilgard occupied the chair of geology at the University of Michigan from 1873 to 1875, when he was appointed professor of agriculture at the University of California. He was also made director of the California Agricultural Experiment Station and continued actively in the work of these positions until his retirement in 1909. Hilgard's studies of the soils of the humid and arid regions of the United States in their chemical, physical, and geological relationships to agriculture laid the foundation of modern soil science. He prepared a report on the soils of the cotton-growing states for the Tenth Census. His treatise on "The Relations of

Soil to Climate," published by the United States Department of Agriculture in 1892, was reprinted in both France and Germany. A later volume upon "Soils," comprising the results of his extensive life studies in this field, was published in 1906. Hilgard was one of the group of chemists who attended the Priestley Centennial in 1874.

GEORGE C. CALDWELL.—Another prominent chemist, influential in helping to lay the foundations of agricultural chemistry in America, was G. C. Caldwell (1834–1907), President of the AMERICAN CHEMICAL SOCIETY in 1892. He obtained his first instruction in chemistry at Harvard University from which he graduated in 1855. After attending the College of Agriculture at Cirencester, England, he studied under Wöhler and Goessmann at Göttingen University where he obtained his doctor's degree in 1857. Upon returning to the United States he taught chemistry at the Pennsylvania State College of Agriculture, of which he became vice president. In 1867 he was appointed professor of agricultural chemistry at Cornell University, which had just been founded. He afterwards became head of the Chemical Department of Cornell, which underwent a most phenomenal growth under his direction.

Caldwell's "Agricultural Chemical Analysis," published in 1869, was the first work upon this subject in the English language and remained for many years a standard treatise. Another important contribution was Caldwell's account of "The More Notable Events in the Progress of Agricultural Chemistry since 1870,"[1] in which the work of Armsby, Atwater, Babcock, Chittenden, Collier, Hilgard, King, Neale, Osborne, Scovell, Stone, Whitney, Wiley, Woods, and other American investigators is carefully reviewed.

Federal and State Workers

A very important factor in the growth of agricultural chemistry in America during the past fifty years was the development of chemical work in the United States Department of Agriculture, which was established in 1862. Twenty years previous to this date the United States Patent Office began publishing annual reports upon agriculture which contained, among other articles, miscellaneous contributions by L. C. Beck, J. C. Booth, T. G. Clemson, Ebenezer Emmons, C. T. Jackson, J. von Liebig, C. Morfit, J. P. Norton, C. U. Shepard, and other scientists upon the chemistry of soils and fertilizers; the chemical composition of grains, vegetables, and fruits; and the applications of chemistry

[1] *J. Am. Chem. Soc.*, **14**, 83 (1892).

to various branches of agricultural technology. At about this period several of the states began to establish departments of agricultural chemistry, the first to take steps in this direction being Maryland, whose legislature at the session of 1847–1848 created the office of state agricultural chemist with James Higgins as the first appointee. W. W. Mather (1804–1859), who in his work in 1835 upon the salts of aluminum made the first atomic weight determination in the United States, was agricultural chemist for Ohio from 1850 to 1854.

The first chemist of the United States Department of Agriculture was C. M. Wetherill (1825–1871), who obtained his training under Liebig at Giessen and began work for the Government in 1862. Following him were Henry Erni, Thomas Antisell, and R. T. Brown.

WILLIAM MCMURTRIE.—In 1873 William McMurtrie (1851–1913), President of the AMERICAN CHEMICAL SOCIETY in 1900, was appointed chief chemist of the Department of Agriculture and retained this office until 1878. He then served as agricultural technologist of the Department until 1882, when he accepted the professorship of chemistry at the University of Illinois. In 1888 he accepted a position as consulting chemist of the Royal Baking Powder Company, of which he afterwards became manager and vice president. Numerous reports upon wine production, sumac, beet sugar, textiles, guano, and other subjects indicate the extent of Dr. McMurtrie's interest in agricultural chemistry.

PETER COLLIER.—Peter Collier, a pupil of S. W. Johnson, succeeded McMurtrie as chief chemist of the Department of Agriculture but resigned this position in 1883, afterwards becoming director of the New York Agricultural Experiment Station at Geneva. Dr. Collier is best known for his extensive researches and publications upon sorghum.

HARVEY W. WILEY.—In 1883 H. W. Wiley (1844–), President of the AMERICAN CHEMICAL SOCIETY in 1893 and 1894, was appointed chief chemist of the Department of Agriculture. The Chemistry Division of the Department, when he assumed its direction, was located in two small rooms in the basement of the old agricultural building and had a personnel of only three, which number had expanded at the time of his resignation in 1912 to over five hundred.

The impress which Dr. Wiley gave to the work of the Bureau of Chemistry and to agricultural chemistry generally during the twenty-nine years of his governmental service has been of a lasting character. His series of annual reports upon the sugar beet is one

of the best examples of an agricultural chemical survey of a crop. His numerous bulletins upon the composition and technology of human foods are still authoritative after more than a quarter of a century. By his publications upon the adulteration and debasement of foods he secured, after years of strong opposition by powerful interests, the final passage of the federal food and drugs act of 1906, one of the finest pieces of constructive legislation ever enacted.

Another important event in the history of agricultural chemistry in America during the past fifty years was the founding of the Association of Official Agricultural Chemists, and in the work of that society Dr. Wiley has played a conspicuous part. In 1880 J. T. Henderson, commissioner of agriculture for Georgia, issued an invitation for prominent American agricultural chemists to meet in Washington, on July 28, at the Department of Agriculture, for the purpose of securing greater uniformity in the methods of analyzing commercial fertilizers. A second meeting, under the chairmanship of C. A. Goessmann, was held at Boston on August 27, 1880, as a subsection of the American Association for the Advancement of Science, and a third meeting convened at Cincinnati on August 18, 1881. In these early meetings trade chemists and official chemists took equal part, but it soon became evident that coöperation between these discordant elements was impossible and no further meetings of this preliminary organization were held. Finally, at the meeting of the American Association for the Advancement of Science at Philadelphia in 1884, the present Association of Official Agricultural Chemists was organized on September 9 under the initiative of H. W. Wiley, H. C. White, E. H. Jenkins, J. A. Myers (1853–1901), C. W. Dabney, and others, with S. W. Johnson as the first president. Dr. Wiley was elected the second president in 1886 and G. C. Caldwell the seventh president in 1891. These three presidents of the Association of Official Agricultural Chemists have also been Presidents of the AMERICAN CHEMICAL SOCIETY. Dr. Wiley has the unique distinction of having attended all the forty-one annual meetings of the Association of Official Agricultural Chemists. He was secretary of the association from 1890 until 1913 and honorary president from 1913 until the present time.

The work of the Association of Official Agricultural Chemists has expanded from the unification of methods for analyzing fertilizers, which was the sole purpose of the first meeting, to the chemical examination of all classes of agricultural products, and its official methods of analysis are regarded as authoritative in all parts of the world. By his work in this association and by

his three-volume "Principles and Practices of Agricultural Analysis," Dr. Wiley has rendered this branch of agricultural chemistry most valuable service.

STEPHEN M. BABCOCK.—Another distinguished octogenarian and connecting link between the old order and the new in American agricultural chemistry is S. M. Babcock (1843–). After graduating from Tufts College in 1866, he taught chemistry for several years and then took a postgraduate course at Göttingen, where he received his doctor's degree in 1879. He was chemist of the New York Agricultural Experiment Station at Geneva from 1882 to 1888, and then accepted a call to the University of Wisconsin, where he filled the dual position of professor of agricultural chemistry and chief chemist of the Agricultural Experiment Station until his retirement in 1913 as professor emeritus. Babcock is distinguished for his researches in dairy chemistry. His invention of the famous Babcock test for determining fat in milk is one of the best examples of the practical usefulness of chemistry to agriculture. The simplicity of the test placed it within the reach of every farmer and it sprang immediately into universal use. 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.

By his work upon the fermentation of cheese and in plant physiology Professor Babcock has made other important contributions to agricultural chemistry. He took a prominent part in the early meetings of the Association of Official Agricultural Chemists and was president of that organization in 1893.

WILBUR O. ATWATER.—A special department of agricultural chemistry in which American scientists have won great distinction is that of human and animal nutrition. The chemist who laid the foundation of exact investigations in this field in the United States was W. O. Atwater (1844–1907), whose work upon human nutrition is described in Chapter X by Graham Lusk. Atwater during his studies abroad familiarized himself with the work of European agricultural experiment stations and after his return to the United States immediately lent his support to the efforts of S. W. Johnson to establish an agricultural experiment station in

Connecticut after European models. The first result of this movement, as already stated, was the establishment of the first state agricultural experiment station in the United States at Middletown on July 2, 1875, with Atwater as director.

Although the Middletown experiment station was discontinued after two years, Atwater continued to occupy himself with agricultural chemical investigations. He organized an extensive series of field experiments with fertilizers and, together with his assistant, the late C. D. Woods (1856–1925), demonstrated that free atmospheric nitrogen is assimilated by leguminous crops. This work, which was reported at meetings of the American Association for the Advancement of Science in 1881 and 1882, is regarded by many as the first convincing proof of this important function of the legumes.

Atwater continued to keep in closest touch with the experiment station movement and became the chief advocate of a general law for the federal support of agricultural investigations in all the different states. His efforts contributed largely to the passage of the famous Hatch Act of 1887, which granted fifteen thousand dollars annually to each state and territory for the maintenance of one or more agricultural experiment stations. Under this provision Connecticut awarded half of the income which it received under the Hatch Act to the previously established experiment station at New Haven, of which S. W. Johnson was director, and half to the establishment of a new experiment station at Storrs, with Atwater as director.

There was a widespread belief at the beginning that the chief purpose of the agricultural experiment stations was the regulatory function of preventing the adulteration of commercial fertilizers. Atwater, however, was strongly opposed to this narrow opinion, as is shown by his declaration in the same year that the Hatch Act was passed: "The future usefulness of the stations will depend upon what they discover of permanent value, and this must come largely from the most abstract and profound research; to forget this will be fatal." As the stations began to take up their more proper experimental functions, the chemical control of fertilizers, feeding stuffs, food products, insecticides, etc., became more and more subordinated to investigational work in crop and animal production. In many states the experiment stations have been entirely relieved of control work by the transference of their former regulatory activities to the state chemist.

In 1888, at the request of Commissioner Coleman, Professor Atwater, without relinquishing his other duties, established the

federal Office of Experiment Stations of which he became the first director.

HENRY P. ARMSBY.—A direct outcome of Atwater's calorimetric investigations upon human beings was the development of similar researches upon farm animals by H. P. Armsby (1853–1921) at the Pennsylvania Agricultural Experiment Station. Armsby's prominence as the leading American authority upon the nutrition of farm animals dated from the publication of his "Manual of Cattle Feeding" in 1880, while he was chemist of the Connecticut Agricultural Experiment Station. This work caused the study of animal nutrition, which had hitherto been largely neglected in the United States, to be considered with much greater attention.

With the passage of the Hatch Act in 1887 Armsby became the first director of the Pennsylvania Agricultural Experiment Station, at State College, and retained this position during the next twenty years. In this period he gave an increasing amount of attention to the scientific feeding of farm animals, with the result that in 1898 the United States Department of Agriculture provided means for erecting at State College a special respiration calorimeter, of the Atwater-Rosa type, for studying the food requirements of live stock. The first experiments with the new apparatus were begun in the winter of 1901–1902, and as the work progressed the possibilities which it afforded of accurately determining the energy requirements of farm animals became more and more apparent. With the growing realization of the importance of the work it was finally decided to detach the animal nutrition investigations from the other activities of the Pennsylvania Experiment Station and to organize it as a separate unit. This led in 1907 to the establishment of the Pennsylvania State College Institute of Animal Nutrition of which Armsby was made director following his resignation as head of the Experiment Station.

Armsby's contributions to the science of animal nutrition have been of the greatest value. He devoted many years to a study of the economic need of converting the numerous agricultural wastes that are unsuited for human food into meat and milk. He pointed out the vast losses of energy that are involved in diverting products which are suitable for direct human consumption to the feeding of farm animals. His policy for the conservation of food materials during the World War was based in fact upon the economic adjustment of the supplies of human and animal foods.

Armsby's chief contribution to the science of animal nutrition was his employment of net energy as a basis for measuring the

nutritive value of food materials. According to this conception the difference between the gross energy of the food before consumption and that expended and lost in the process of its utilization represents the net energy value of the food for purposes of maintenance and production. Armsby's determinations of the net energy values of the principal American feeding stuffs and his use of these in place of the old digestion coefficients for computing the rations of farm animals form one of the most important contributions to agricultural chemistry which has been made in recent years. Armsby's researches in the field of animal nutrition have been summarized in several books—"Principles of Animal Nutrition," "The Nutrition of Farm Animals," "The Conservation of Food Energy" (published in 1918 with reference to the food situation during the World War), and "The Animal as a Converter of Matter and Energy," which was prepared after Armsby's death by his collaborator, C. R. Moulton, as one of the AMERICAN CHEMICAL SOCIETY Monograph Series.

The work initiated by Armsby has been continued at State College since 1922 by E. B. Forbes, the present director of the Institute of Animal Nutrition, in collaboration with Armsby's former associates, J. A. Fries and W. W. Braman.

Later Developments

The work in American agricultural chemistry which has thus far been described was conducted mostly by men who were born before 1850. These were the chemists who laid the broad foundations of the science as it is being applied to the needs of American agriculture today. But the description of their accomplishments has supplied only the general background of the picture, which is still lacking in many important details. The number of workers in this field who were born since 1850 is so large and the range of their activities so diverse that it will be possible in the remainder of this review to discuss only very briefly a few of the present-day applications of chemistry to American agriculture.

A great difficulty in making a survey of this character is the difference of opinion which prevails respecting the demarcations of agricultural chemistry. The latter, in its generally accepted meaning, may be defined as that branch of chemistry which treats of the chemical composition of soils, crops, and animals, and of the mutual chemical relations of these in so far as they concern the production of the means of human subsistence and welfare. There is no field of applied chemistry which is so broad in its scope or so comprehensive in its bearings as that pertaining

to agriculture, including, as it does, not only many branches of chemistry but touching also upon mineralogy, physics, meteorology, plant and animal physiology, mycology, and other correlated sciences.

It is held by many that agricultural chemistry relates solely to the production of raw materials, such as grain, vegetables, fruit, live stock, milk, hides, wool, etc., and not to their utilization. Yet in many cases the manufacture of butter, cheese, vinegar, sirup, sugar, canned goods, etc., from raw materials is performed directly on the place of production and constitutes an integral part of the farm operations. The opinion has also been expressed that human nutrition and the chemical control of human foods lie outside the province of agricultural chemistry. Yet the nutritive needs of the farmer and his family must be considered as essential factors in the successful management of the farm, and the farmer, moreover, cannot ignore the regulatory requirements which govern the sale of his milk and other produce. Agricultural chemistry is, therefore, closely concerned with the utilization and disposition of manufactured products of farm origin, although it is less actively engaged in these phases of the subject than in the production of raw materials.

A compilation of projects of American agricultural experiment stations, prepared in 1923 by E. R. Flint (1864–1926), shows that of the investigations which involve chemistry 188 relate to soils; 150 to fertilizers; 111 to animal nutrition; 73 to insecticides, fungicides, etc.; 57 to dairy products; 49 to plant nutrition; and 45 to various miscellaneous studies of foods, etc. These figures show in a general way the relative stress which is now being placed by American experiment stations upon certain applications of chemistry to agriculture.

Soils.—In point of utility the investigations of H. J. Wheeler and his co-workers at the Rhode Island Experiment Station upon acid soils are of exceptional importance. The practical value of this work to American agriculture in restoring fertility to barren lands by the addition of lime is incalculable. The study of the causes, effects, and elimination of soil acidity is a question that has engaged a large number of American chemists: William Frear (1860–1922) in Pennsylvania; B. L. Hartwell in Rhode Island; S. D. Conner and H. A. Noyes in Indiana; W. H. MacIntire in Tennessee; D. R. Hoagland in California; Emil Truog in Wisconsin; J. K. Plummer in North Carolina; and F. P. Veitch and E. T. Wherry at the Bureau of Chemistry are only a few of those who have made contributions to this subject. The injurious

effects of soluble salts of aluminum, iron, and manganese upon crops which are grown in acid soils has been investigated, among others, by R. W. Ruprecht in Massachusetts; by Emil Truog in Wisconsin; by B. L. Hartwell, F. R. Pember, and P. S. Burgess in Rhode Island; and by S. D. Conner and J. S. Abbott in Indiana. The effect of salts and of heat upon soils and the transformation of nitrogen in soils have been studied by W. P. Kelley in Hawaii and California. T. L. Lyon has made experiments with lysimeters and has investigated the influence of higher plants on bacterial processes in soils.

The causes, effects, and removal of alkalinity in soils have continued to attract the attention of chemists in the western states since the early investigations of E. W. Hilgard. The recent work of P. L. Hibbard in California upon reclaiming alkali soils by leaching with water and gypsum and the studies of alkali and plant food under irrigation and drainage by C. W. Botkin in New Mexico are mentioned in this connection.

The processes of oxidation, reduction, nitrification, denitrification, etc., by which the organic matter of soils is transformed by bacteria and other agencies, have been studied by E. B. Voorhees and J. G. Lipman in New Jersey; by W. A. Withers and by L. G. Willis in North Carolina; by G. S. Fraps in Texas; and many others. The first award of the Nichols Medal by the New York Section of the AMERICAN CHEMICAL SOCIETY was made to E. B. Voorhees for his "Studies in Denitrification."[1] The organic substances which are formed in soils by the decay of plant and animal residues have been extensively investigated by Oswald Schreiner and his collaborators, E. C. Shorey, J. J. Skinner, M. X. Sullivan, H. S. Reed, B. E. Brown, and E. C. Lathrop of the Bureau of Soils. The hypothesis of toxic exudates from the roots of crops, as a cause of unproductiveness in soils, originally proposed by the Bureau of Soils, attracted considerable attention at the time it was announced but has not met with general acceptance. The important work of F. K. Cameron of the Bureau of Soils upon "The Soil Solution" has been noted in Chapter VII upon "Physical Chemistry," by W. D. Bancroft.

WATERS.—In the more or less arid agricultural regions of the country the chemical composition of the water which is used for irrigating land or watering livestock is of considerable importance. The subject has been studied from various angles by E. W. Hilgard, R. H. Loughridge, W. P. Kelley, and C. B. Lipman in California; by R. H. Forbes and W. W. Skinner in Arizona; by

[1] *J. Am. Chem. Soc.*, **24**, 785 (1902).

J. E. Greaves, Robert Stewart, and J. A. Widtsoe in Utah; by W. P. Headden in Colorado; by F. W. Traphagen in Montana; by G. S. Fraps in Texas; and by numerous others.

FERTILIZERS.—Chemical analyses and field tests of fertilizers have engaged the attention of American agricultural experiment stations since the time of their establishment. The agricultural station at State College, Pennsylvania, has a record of field tests beginning with 1882 which are the oldest extensive experiments with fertilizers now in progress in America. The field tests upon fertilizers conducted by William Frear in Pennsylvania; by E. B. Voorhees and J. G. Lipman in New Jersey; by H. J. Wheeler and B. L. Hartwell in Rhode Island; by C. E. Thorne in Ohio; by C. G. Hopkins (1866–1919) in Illinois; by Harry Snyder in Minnesota; by W. C. Stubbs (1843–1924) in Louisiana; and by F. T. Shutt and C. E. Saunders in Canada are mentioned simply as typical examples of the work which has been conducted in this field. A very good summary of fertilizer experimentation in America is contained in "Soil Fertility and Permanent Agriculture" by C. G. Hopkins, distinguished for his work upon the role of phosphorus in crop production and upon the relation of phosphates to permanent fertility. The volume upon "Fertilizers" by E. B. Voorhees is also worthy of mention.

As a consequence of the threatening shortage of fertilizers during the World War much attention was given by American chemists to developing domestic sources of potassium salts and to perfecting methods for nitrogen fixation. The Bureau of Soils and the Nitrogen Fixation Laboratory of the United States Department of Agriculture have taken a prominent part in the improvement of processes for manufacturing concentrated potassic and nitrogenous fertilizers.

A study of the fertilizing value of previously neglected elements is engaging the attention of various American chemists. The relation of sulfur to soil fertility has been investigated by W. E. Tottingham in Wisconsin; by G. A. Olson in Washington; by J. G. Lipman in New Jersey; and others. J. S. McHargue of Kentucky has made valuable studies regarding the effects of manganese upon plant growth.

ANIMAL NUTRITION.—Feeding experiments with farm animals for working, or for the production of meat, milk, etc., have been undertaken at most of the American agricultural experiment stations, with the major interest in New York, Pennsylvania, Illinois, Wisconsin, Missouri, and Minnesota. The results of this work are too compendious for the mention of particular

workers. The first compilation upon the composition of American feeding stuffs was made by E. H. Jenkins of Connecticut in 1879. More extensive summaries were made later by W. H. Jordan of New York and J. B. Lindsey of Massachusetts. A very complete "Compilation of Analyses of American Feeding Stuffs" was published by E. H. Jenkins and A. L. Winton as Experiment Station Bulletin No. 11 of the United States Department of Agriculture. Tables of the composition and digestibility of American feeding materials are also contained in the treatise of W. A. Henry and F. B. Morrison of the Wisconsin station upon "Feeds and Feeding."

The subject of mineral metabolism in farm animals has been studied at various agricultural experiment stations. E. B. Forbes at the Ohio station has studied the metabolism of phosphorus and other mineral ingredients in cows and swine. The metabolism of calcium in laying hens has been investigated by G. D. Buckner, J. H. Martin, and A. M. Peter at the Kentucky station. C. R. Moulton, P. F. Trowbridge, and L. D. Haigh have made exhaustive studies in Missouri upon the distribution of ash and phosphorus in the bodies of cattle. The importance of iodine in the diet, with special reference to the prevention of goiter in animals, has been studied by G. E. Smith; by E. B. Hart and Harry Steenbock of Wisconsin; by J. F. McClendon of Minnesota; and many others. A correlation of manganese content with vitamin potency in the organs of animals has been noted by J. F. McHargue at the Kentucky station. In addition to the names mentioned, C. H. Hunt and A. R. Winter of the Ohio station, H. G. Miller of Oregon, and many others have studied the significance of particular mineral constituents in animal nutrition.

The important researches of T. B. Osborne at the Connecticut station upon the chemistry of the vegetable proteins and the work of American chemists upon vitamins and other phases of animal nutrition are fully discussed in Chapter X by Graham Lusk.

Dairy Products.—Great advances have been made in the United States during the past fifty years in the applications of chemistry to dairying and to dairy products. L. L. Van Slyke has investigated the chemistry of cheese-making, the proteins of milk products, and the chemical changes which are produced in the souring and curdling of milk. Results upon the preservation of milk by charging it with carbon dioxide under pressure were published in 1907 by L. L. Van Slyke and A. W. Bosworth. More recently the introduction of commercial processes for the pres-

ervation of milk, butter, and ice cream by means of carbon dioxide has led to a general study of the carbonation of dairy products at the Illinois Experiment Station. E. B. Hart, E. H. Farrington, F. W. Woll (1865–1922), and their co-workers at the Wisconsin station have devoted much attention to the chemistry of dairy products. The chemistry of rancidity in butter fat was investigated by C. A. Browne at the Pennsylvania station in 1899 and more recently by G. E. Holm of the United States Bureau of Dairying. E. B. Holland has studied the composition of butter fat and its modification as a result of feeding. The chemistry and physical chemistry of churning is being investigated at the Minnesota station. G. C. Supplee and J. T. Cusick of the Cornell Experiment Station and H. H. Sommer and B. J. Smit of the Wisconsin station have found that the abnormal fishy flavor of butter is due to the decomposition of lecithin into trimethylamine. The yellow pigment of milk fat and its relation to the plant carotins have been exhaustively studied by L. S. Palmer and C. H. Eckles at the Minnesota station. The clarification and pasteurization of milk, the preparation of milk powders and modified milks, methods for improving ice cream, the manufacture of foreign types of cheese, the utilization of whey, the reduction of butter fat losses in churning, and numerous other problems in dairy technology are being actively investigated by American chemists.

Great progress has also been made in the improvement of methods for analyzing dairy products. The apparatus of J. J. Mojonnier for determining fat in dairy products by the modified Röse-Gottlieb method has found extensive use. Other improvements in methods and apparatus for analyzing milk and its products have been made by J. C. Baker, E. B. Hart, Julius Hortvet, G. E. Patrick (1851–1916), G. C. Supplee, L. L. Van Slyke, and W. O. Walker—to mention only a few of many names.

Crops.—In the chemistry of crops American investigators have made contributions in numerous fields. J. P. Norton was one of the earliest to specialize in the chemistry of particular crops and won a prize of fifty guineas eighty years ago from the Scotch Highland Society for his essay upon "The Oat." Of the more recent chemical studies upon cereals may be mentioned the work of Clifford Richardson at the Bureau of Chemistry, of Harry Snyder in Minnesota, and of E. F. Ladd (1859–1925) in North Dakota upon wheat; of C. G. Hopkins in Illinois upon corn; and of B. B. Ross, C. A. Browne, C. C. McDonnell, and others upon rice. Investigations upon the chemistry of apples and other

fruits have been made by W. B. Alwood, W. D. Bigelow, F. C. Blanck, C. A. Browne, E. M. Chace, A. W. Christie, H. C. Gore, and many others. C. H. Jones has studied the chemistry of the maple tree and maple sap.

Chemical investigations upon the sugar cane and its products in Louisiana were initiated by Avequin in 1840, but were first followed up intensively with the establishment by W. C. Stubbs (1843–1924) of the Louisiana Sugar Experiment Station in 1885. Among those who have conducted agricultural chemical work at this station may be mentioned R. E. Blouin, J. F. Brewster, C. A. Browne, C. E. Coates, W. E. Cross, J. M. Schneller, P. A. Yoder, and F. W. Zerban. Similar studies have been conducted in Hawaii by H. P. Agee, Noel Deerr, C. F. Eckart, Walter Maxwell, and R. S. Norris. Investigations upon sugar crops and sugars have also been conducted at the United States Bureau of Chemistry by D. H. Brauns, C. A. Browne, A. H. Bryan (1874–1920), C. A. Crampton, (1858–1915), H. C. Gore, C. S. Hudson, H. S. Paine, S. F. Sherwood, G. L. Spencer (1858–1925), C. F. Walton, Jr., H. W. Wiley, and many others. A study of the Jerusalem artichoke as a source of levulose has been undertaken at the United States Bureau of Standards by F. J. Bates, R. F. Jackson, M. J. Profitt, and C. J. Silsbee.

The chemistry of the cotton plant has been investigated, or reported upon, by J. B. McBryde and W. H. Beal; by F. B. Power and V. K. Chesnut; by H. C. White; by W. A. Withers (1864–1924); and by many others. The chemistry of tobacco growing and curing has been studied by William Frear in Pennsylvania and E. H. Jenkins in Connecticut. Of the more special studies in phytochemistry may be mentioned the work of F. B. Power and V. K. Chesnut upon the odorous principles of fruits, of G. S. Jamieson upon the vegetable oils, of E. K. Nelson upon the vegetable acids, and of R. J. Anderson upon the pigments of the grape. The chemistry of the pectins has been studied by E. K. Nelson, W. H. Dore, C. P. Wilson, L. W. Tarr, and others. The studies of L. S. Palmer and his co-workers upon the caritinoids and related pigments are included in his exhaustive review of this subject in the AMERICAN CHEMICAL SOCIETY Monograph Series. The chemical composition of American honeys, as influenced by different floral nectars, has been investigated by C. A. Browne, A. H. Bryan (1874–1920), and others. The modification of the composition of wheat and other cereals by fertilization has been studied by J. A. LeClerc and Jehiel Davidson.

INSECTICIDES AND FUNGICIDES.—The prevention of the enor-

mous losses to agriculture from insect pests and fungous diseases is a subject in which American chemists have taken a leading part. Paris green, which was introduced shortly before 1870 to combat the potato bug, was the first important chemical to be used for destroying insects, but is now surpassed as a general insecticide by other arsenical preparations. Lead arsenate, first employed in Massachusetts in 1892 to destroy the gypsy moth, is probably the most generally used arsenical insecticide. Calcium arsenate, which exceeds other insecticides in quantity production, is mostly employed for combating the cotton boll weevil, being first used for this purpose in 1918. The chemistry of the various arsenicals has been investigated by J. K. Haywood, C. C. McDonnell, C. M. Smith, R. H. Robinson, H. V. Tartar, and others. For destroying insects in grain, carbon disulfide is the most extensively used fumigant but has the serious objection of inflammability. Hydrocyanic acid, introduced as a fumigant by the United States Department of Agriculture in 1886, is highly effective but dangerous. Efforts to develop less hazardous fumigants have been made by J. E. Neifert, F. C. Cook (1877–1923), R. C. Roark, and others. Chloropicrin and ethyl acetate have shown some promise in this connection. The perfection of various petroleum emulsions for combating sucking insects and the development of cheap effective substitutes for nicotine, pyrethrum, and other expensive insecticides are receiving considerable attention. The use of organic substances for attracting or repelling insects is also being investigated. Amyl acetate has been employed in poisoned baits as an attractant for grasshoppers and geraniol has been proposed as a means of luring Japanese beetles into traps. Trimethylamine, discovered by F. B. Power and V. K. Chesnut among the odorous constituents of the cotton plant, has been found to attract the boll weevil.

Bordeaux mixture, discovered by Millardet of France in 1880, is the most extensively used fungicide in the United States. The chemistry of its composition and action has been recently investigated by F. C. Cook. Lime-sulfur solution is another fungicide which has been widely studied by American chemists, more especially by R. W. Thatcher, J. K. Haywood, L. L. Van Slyke, C. C. Hedges, and A. W. Bosworth. The effectiveness of copper carbonate and other chemicals in preventing smuts of grain is being investigated at various experiment stations.

The Louisiana enactment of 1890 which regulated the purity of Paris green was the first state insecticide law. At present twenty-eight states have laws relating to insecticides and fungicides.

E. D. Sanderson, director first of the New Hampshire and later of the West Virginia Experiment Station, and J. K. Haywood of the Bureau of Chemistry were largely instrumental in securing the passage of the federal law of 1910, which has had a most beneficial effect upon the improvement of insecticides and fungicides in the United States.

FOOD TECHNOLOGY.—Much attention is being given in the United States to the chemistry and technology of foods and other agricultural products by industries, coöperative research laboratories, experiment stations, and various institutions of learning. The Louisiana Sugar Experiment Station, the Minnesota State Testing Mill for examining wheat, the American Institute of Baking, the National Canners Association, the Meat Packers Institute, the Mellon Institute, the Boyce-Thompson Institute, the research laboratories of the California Fruit Growers Exchange, the fruit and vegetable laboratory of the University of California, the Tanners' Research Laboratory of the University of Cincinnati, the research laboratory of the Glass Container Association, the New York Sugar Trade Laboratory, and the various fruit, vegetable, cereal, meat, dairy, and other special laboratories of the United States Department of Agriculture are a few examples of institutions which are conducting chemical and technological studies upon the numerous special products of agricultural origin. Many investigations of this character have also been performed by private enterprise. The researches of Arno Behr (1846–1921) upon the utilization of corn products, and of David Wesson upon the utilization of cottonseed products as food are illustrations of industrial chemical work which has been of the greatest benefit to American agriculture.

FOOD CONTROL.—The control of the purity of milk, butter, cheese, grain, and numerous other agricultural products engages the attention of thousands of chemists in the various municipal, state, and federal laboratories of the United States. Following the passage of different state laws and of the federal food and drugs act of 1906, there has been a great improvement in the character of the food products which are now sold in the United States. Among the chemists who have taken an active part in improving the purity of the Nation's food supplies may be mentioned J. S. Abbott, C. L. Alsberg, E. M. Bailey, R. W. Balcom, H. E. Barnard, W. D. Bigelow, F. C. Blanck, L. P. Brown, R. E. Doolittle (1874–1926), P. B. Dunbar, F. L. Dunlap, R. L. Emerson, G. G. Frary, William Frear, W. S. Frisbie, Elton Fulmer (1864–1916), W. C. Geagley, W. F. Hand, B. R. Hart, R. W. Hilts

(1879–1924), Julius Hortvet, C. D. Howard, M. E. Jaffa, E. H. Jenkins, E. F. Ladd (1859–1925), A. E. Leach (1864–1917), H. M. Loomis, H. C. Lythgoe, I. L. Miller, A. S. Mitchell, A. E. Paul, I. K. Phelps, W. W. Randall, Clifford Richardson, R. W. Redfield, R. E. Rose, M. A. Scovell (1855–1912), A. F. Seeker (1878–1919), W. W. Skinner, J. P. Street, L. M. Tolman, H. A. Weber (1845–1914), H. W. Wiley, and A. L. Winton—to name only a few of the prominent workers in this field.

Chemistry in the Direction of Agricultural Research

Limitations of space prevent the enumeration of many other important subjects in which chemistry is being applied to agriculture. The recent work, "Chemistry in Agriculture," edited by J. S. Chamberlain for the Chemical Foundation, contains sixteen chapters by various specialists upon certain applications of chemistry to American agriculture. The recent bequest of Mrs. Herman Frasch for research in agricultural chemistry is an evidence of the growing realization of the value of work in this field.

Perhaps the best evidence of the importance of chemistry to agriculture is the prominent part which chemists have taken in directing agricultural research. The following table gives a list of chemists who have been directors or acting directors of American agricultural experiment stations.

Chemists Who Have Been Directors or Acting Directors of American Agricultural Experiment Stations

NAME	STATION	PERIOD OF OFFICE
H. P. Agee	Hawaii, Sugar Planters	1913–
H. P. Armsby	Pennsylvania	1887–1907
H. P. Armsby	Pennsylvania Institute of Animal Nutrition	1907–1921
W. O. Atwater	Connecticut, Middletown	1875–1877
W. O. Atwater	Connecticut, Storrs	1887–1901
J. M. Bartlett*	Maine	Dec., 1920–Apr., 1921
H. B. Battle	North Carolina	1887–1897
R. E. Blouin	Hawaii, Sugar Planters	1900–1901
G. C. Caldwell	New York, Cornell	1879–1888
G. W. Carver	Alabama, Tuskegee	1900–
P. Collier	New York, Geneva	1887–1895
G. H. Cook	New Jersey	1880–1889
W. W. Cooke	Vermont	1887–1893
J. T. Crawley	Porto Rico, Sugar Producers	1910–1914
C. W. Dabney, Jr.	North Carolina	1880–1887
C. W. Dabney, Jr.	Tennessee	1887–1890
C. T. Dowell	Oklahoma	1921–
C. F. Eckart	Hawaii, Sugar Planters	1901–1913
John Fields	Oklahoma	1899–1906
E. B. Forbes	Pennsylvania Institute of Animal Nutrition	1922–
R. H. Forbes	Arizona	1899–1918
C. P. Fox	Idaho	1894–1896

Chemists Who Have Been Directors or Acting Directors of American Agricultural Experiment Stations (Concluded)

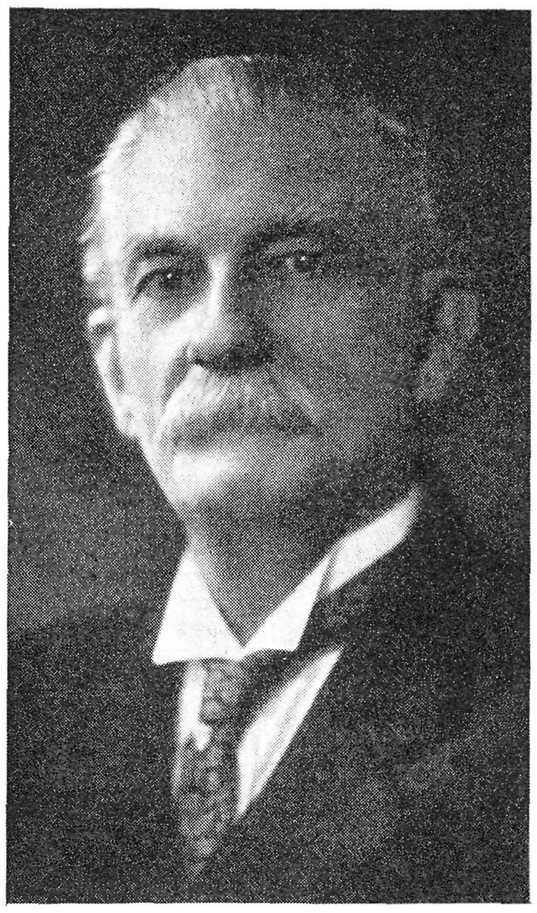
NAME	STATION	PERIOD OF OFFICE
C. A. Goessmann	Massachusetts	1882–1895
Arthur Goss	Indiana	1903–1917
H. H. Harrington	Texas	1906–1911
F. S. Harris	Utah	1917–1921
B. L. Hartwell	Rhode Island	1912–
E. W. Hilgard	California	1874–1908
J. L. Hills	Vermont	1893–
H. A. Huston	Indiana	1902–1903
W. L. Hutchinson	Mississippi	1898–1910
E. H. Jenkins	Connecticut	1900–1923
S. W. Johnson	Connecticut, New Haven	1877–1899
W. H. Jordan	Maine	1885–1896
W. H. Jordan	New York, Geneva	1896–1921
J. H. Kastle	Kentucky	1912–1916
B. W. Kilgore	North Carolina	1901–1907; 1912–1925
H. G. Knight	Wyoming	1910–1918
H. G. Knight	Oklahoma	1918–1921
H. G. Knight	West Virginia	1922–
A. R. Ledoux	North Carolina	1877–1880
J. G. Lipman	New Jersey	1911–
T. L. Lyon*	Nebraska	1899–1905
Walter Maxwell	Hawaii, Sugar Planters	1895–1900
J. M. McBryde	South Carolina	1887–1890
J. M. McBryde	Virginia	1892–1904
C. A. Mooers	Tennessee	1923–
F. B. Morrison*	Wisconsin	1924–1925 (5 mos.), 1926
F. W. Morse*	New Hampshire	1912–1913
F. W. Morse*	Massachusetts	1918–1920
J. A. Myers	West Virginia	1887–1897
A. T. Neale	Delaware	1888–1906
H. H. Nicholson	Nebraska	1890–1893
H. J. Patterson	Maryland	1898–
A. M. Peter	Kentucky	Aug., Oct., 1912;* Jan.–Feb., 1915;* 1916–1917
J. P. Schweitzer	Missouri	1888–
M. A. Scovell	Kentucky	1885–1912
J. H. Shepard	South Dakota	1895–1900
Longfield Smith	Virgin Islands	1918–1921
H. E. Stockbridge	Indiana	1889–1890
H. E. Stockbridge	North Dakota	1890–1893
W. C. Stubbs	Louisiana	1885–1905
R. W. Thatcher	Washington	1907–1913
R. W. Thatcher	Minnesota	1917–1921
R. W. Thatcher	New York, Geneva	1921–
R. W. Thatcher	New York, Cornell	1923–
P. F. Trowbridge	North Dakota	1918–
L. L. Van Slyke*	New York, Geneva	1895–1896
E. B. Voorhees	New Jersey	1893–1911
H. J. Wheeler	Rhode Island	1900–1912
J. A. Widtsoe	Utah	1900–1905
J. T. Willard	Kansas	1900–1906
W. A. Withers*	North Carolina	1897–1899
C. D. Woods	Maine	1896–1920
P. A. Yoder	Utah	1905–1907

* Acting director.

Conclusion

The impetus which the chemists of America gave to agricultural research a half-century ago has been strong and extensive. Beginning with the fundamental problems of soils and fertilizers the movement extended to the complex fields of plant and animal life until now there is not a single department in the whole province of agriculture that is not permeated with the outlook and influences of chemistry. It was fortunate that the foundations of modern agricultural research were laid by chemists, for they imparted to it a definiteness of method and purpose which otherwise would not have been acquired. But while the elements and the processes which govern their combination form the basis for the existence of soils and crops and animals, the aims of agriculture are not so distinctively chemical as was once supposed. With the growing realization of this, the demarcation of chemistry as a separate branch of agricultural research is now much less evident than was the case twenty or more years ago. Chemistry in its relationship to agriculture has changed from an independent to a coöperative science, and it is in the borderland where it and the other sciences meet that the agricultural scientists of the future will find the greatest opportunities for service and accomplishment.

It may be said in conclusion that as the density of population in the United States increases, greater attention must be given to more intensive methods of agriculture. There must be a greater avoidance of waste, a higher yield of crops, a more economical feeding of animals, and a better utilization of raw materials. In all of these lines of advancement chemistry may be expected to play a role of increasing importance.



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ABRAM A. BRENEMAN
(1847–)

Editor, *Journal of the American Chemical Society* 1884–1893

Alman & Co.

EDWARD HART
(1854–)

Editor, *Journal of the American Chemical Society* 1893–1902

Marshall

ARTHUR B. LAMB
(1880–)

Editor, *Journal of the American Chemical Society* 1917–

AUSTIN M. PATTERSON
(1876–)

Editor, *Chemical Abstracts* 1909–1914

A. A. Breneman attended the Priestley Centennial in 1874.