Dairy Production Research in the United States Department of Agriculture

R. E. Hodgson

Chief, Dairy Husbandry Research Branch
Agricultural Research Service, USDA, Beltsville, Md.

Research, demonstration, and the collection and dissemination of information useful to the dairy farmer have been carried on in the United States Department of Agriculture for about 70 years. The first work was done by the Bureau of Animal Industry. During the last quarter of the 19th century the dairy industry had grown to such prominence in the agricultural economy that Congress enacted legislation to establish a special Dairy Division in the Bureau of Animal Industry to pursue research and education for the benefit of that industry.

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While the dairy industry was making rapid growth at this time, it was at a low state of efficiency. In 1890 there were about 15 million cows kept for milk on farms. Their average production was about 2,700 lb. of milk and 115 lb. of butterfat. Knowledge of feeding and the production of efficient, low-cost feed supplies was limited. There was no testing program to guide farmers in their breeding and feeding operations or in culling poor cows from their herds. Methods of producing milk of high sanitary quality were inadequate.

Departmental Organizations for Dairy Production Research—1895 to 1956

The Dairy Division began functioning July 1, 1895. During the formative years the production work of the new Division developed along several lines, namely, breeding, feeding, and management; animal nutrition; physiology; milk secretion; milk quality improvement; and cow testing.

As the work of the Dairy Division grew, it became increasingly popular in the industry. As early as 1912 various dairy groups began asking for an independent bureau for dairy work. In 1924 Congress passed a law that established the Bureau of Dairying and in 1926 enacted legislation changing the name to the Bureau of Dairy Industry.

By that time the major emphasis was on research and less attention was devoted to introduction and extension. In 1929 three major divisions were pursuing production research in the Bureau: the Division of Dairy Research Laboratories, which conducted work on dairy cattle nutrition, physiology, and milk composition; the Division of Dairy Cattle Breeding, Feeding, and Management, which included the dairy cattle breeding investigations, the field station work, and the Beltsville station feeding and management research; and the Division of Dairy Herd Improvement Investigations, which included the investigational work relating to cow testing. In 1937 the Division of Nutrition and Physiology was organized by separating the nutrition and physiology work from the Division of Dairy Research Laboratories and combining with it the physiological work that was being done in the Division of Breeding, Feeding, and Management. In 1946 the feeding research at Beltsville was transferred from the Division of Breeding, Feeding, and Management to the Division of Nutrition and Physiology.

On January 2, 1954, as a part of the reorganization of the U. S. Department of Agriculture accomplished by Secretary E. T. Benson under authority granted him by Congress in Reorganization Plan No. 2 of 1953, the Bureau of Dairy Industry was abolished and the production research was established in the Dairy Husbandry Research Branch.

The objectives of the Branch program continue to be the investigation, demonstration, and dissemination of useful information to advance the dairy farming industry. The present research staff numbers about 60 technically trained scientists.

The men who have served as chiefs of the Division, Bureau, and Branch and who have been responsible for the dairy production research in the Department from 1895 to the present, and their periods of service, are shown in Table 1.

Research and Demonstration Facilities

The headquarters of the dairy production work from 1895 to 1954 was in the U. S. Department of Agriculture building in Washington, D. C., and since 1954 at the Agricultural Research Center, Beltsville, Md.

When the Dairy Division was first formed, it had no research facilities, and much of its investigational work was done in laboratories provided by the Biochemic Division of the Bureau of Animal Industry. In 1902 the first laboratory facilities were provided in Washington, D. C., for the work of the Dairy Research Laboratories. The facilities used in dairy herd improvement investigations were devel-

TABLE 1

Name of chief	Period of service	Organization name
Major H.E. Alvord	July 1, 1895, to Oct. 1, 1904	Dairy Division, Bureau of Animal Industry
Mr. H. E. Webster	July 1, 1905, to Jan. 1, 1909	Dairy Division, Bureau of Animal Industry
Mr. B. H. Rawl	July 1, 1909, to Feb. 15, 1921	Dairy Division, Bureau of Animal Industry
Dr. C. W. Larson	Feb. 15, 1921, to July 1, 1924	Dairy Division, Bureau of Animal Industry
Dr. C. W. Larson	July 1, 1924, to July 1, 1926	Bureau of Dairying
Dr. C. W. Larson	July 1, 1926, to Jan. 1, 1928	Bureau of Dairy Industry
Dr. L. A. Rogers[1]	Jan. 1, 1928, to Sept. 1, 1928	Bureau of Dairy Industry
Dr. O. E. Reed	Sept. 1, 1928, to Jan. 2, 1954	Bureau of Dairy Industry
Dr. R. E. Hodgson	Jan. 2, 1954, to present	Dairy Husbandry Research Branch, ARS

[1] Served as acting chief.

oped in Washington, where they are located at present.

Beltsville Dairy Station. As the production research programs developed, the need for extensive laboratory and farm facilities became increasingly apparent. In 1910 the Dairy Division acquired a tract of 189 acres of land in nearby Maryland, together with a few usable buildings. This was the beginning of the Beltsville Dairy Research Station. In later years additional land was added to the station until now about 600 acres are available. Experimental barns and other special buildings have been added so that facilities are available now for some 700 to 800 head of cattle. Chemical, bacteriological, physiological, and other types of laboratories are available for the use of about 40 scientists working on various breeding, feeding, physiological, nutritional, and management projects concerned with dairy production.

Departmental Field Dairy Research and Demonstration Stations. In order to meet the ever increasing need for information in the different regions, additional facilities were required. Congress authorized a number of dairy field stations in the less well developed dairy states to enable the Department to better serve these areas. The research at these field stations was planned to produce information especially useful to those areas to improve dairy farming. The number of stations authorized, their location, size, and present status are shown in Table 2.

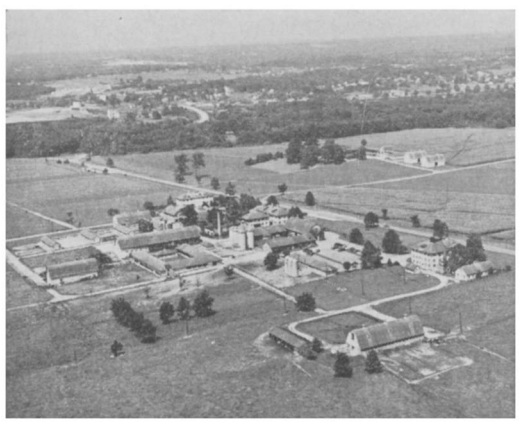

FIG. 1. Aerial view of Bureau of Dairy Industry buildings at the Beltsville Research Center, Beltsville, Maryland.

Cooperative state experiment station research. From the beginning of its work the Dairy Division developed cooperative relations with state experiment stations to carry on some of its research. This policy has been followed to an increasing extent in the following years. In this cooperative work the states generally have provided the facilities. In addition, formal cooperative relations were developed with all of the states dealing with the dairy herd improvement association and sire-proving investigations.

Milk quality work. Early work of the Dairy Division concerned itself with investigations to improve the quality of milk. A lot of this early work dealt with surveys of farms and milk supplies. A bulletin issued in 1897 gave 50 rules for dairy farmers, mainly directed toward producing clean milk. In 1910 a score card for rating dairy farms was developed by Division workers in cooperation with committees of the American Dairy Science Association. This score card is the progenitor of the score card in use today.

From 1912 to 1925 a considerable amount of research was conducted by Ernest Kelly and C. J. Babcock on the causes of abnormal flavors of milk. A special barn was constructed at Beltsville for this work. The effects of unclean vs. clean conditions, of oats, silage, garlic, beet tops, grass silage, and other feeds and materials used in the barn on the flavor and odor of milk were studied, and the results and recommendations were made available in several department publications. Since this extensive research, little has been done on feed flavors except for studying the effect of various silages, especially grass silage, on the flavor and odor of milk.

Dairy herd improvement investigations. The Dairy Division began investigational work to develop the cow testing program (later called the dairy-herd-improvement association pro-

TABLE 2

Department of Agriculture Dairy Field Stations

Location	Date started	Date discontinued	Size of station	Breeds of cattle	Size of herd	Remarks
			Acres			
Jeanerette, La.	1914	——	200	Jersey, Red Sindhi & crossbreds	150	Station cooperative with Louisiana Agricultural Experiment Station since 1914. Research program jointly planned and conducted since 1947.
Huntley, Mont.	1916	——	100	Holstein-Friesian	150	Research program became cooperative with Montana Agricultural Experiment Station in 1946. Station property turned over to Montana by Congressional Act in 1949.
Ardmore, S. D.	1916	1932	250	Holstein-Friesian	40	Station closed because of lack of funds.
Woodward, Okla.	1920	1952	150	Holstein-Friesian	75	Station cooperative with Oklahoma Agricultural Experiment Station since 1921. Closed because of lack of funds.
Mandan, N.D.	1927	1955	627	Holstein-Friesian	60	Station closed because of lack of funds.
Pontiac, S. C.	1928	1947	200	Guernsey	100	Station cooperative with S. C. Agricultural Experiment Station. Closed due to lack of funds. Herd transferred to S. C. Agricultural Experiment Station for cooperative breeding project at Clemson, S. C.
Lewisburg, Tenn.	1928	——	500	Jersey	200	Station and program jointly planned and conducted with Tennessee Agricultural Experiment Station since 1947.
Hannibal, Mo.	1931	1945	150	Jersey	75	Station facilities and part of herd furnished by Missouri Agricultural Experiment Station. Program jointly planned and conducted. Closed due to lack of funds.
Willard, N. C.	1938	——	125	Jersey	75	Station facilities and part of herd provided by North Carolina Department of Agriculture and North Carolina Agricultural Experiment Station. Program jointly planned and conducted with North Carolina Agricultural Experiment Station.
Puyallup, Wash.	1930	1942	100	Holstein-Friesian	100	Station facilities and herd provided by Western Washington Experiment Station. Program jointly planned and conducted with Washington Agricultural Experiment Station. Discontinued because of lack of funds.
Logan, Utah	1930	1941	125	Holstein-Friesian	100	Station facilities and herd provided by Utah Agricultural Experiment Station. Program jointly planned and conducted. Discontinued because of lack of funds.

gram) in 1908. Helmer Rabild, the man who organized the first association in Michigan in 1905, was employed for this work. The development of cow testing involved work in farmers' herds in the states and because of this it was done cooperatively with state extension specialists. The first need was the development of uniform organizational procedures and suitable forms for recording the data needed on the production and related items concerning each individual cow in a herd, which would be acceptable to all states. Considerable investigational work was done by Rabild and later by his successors, J. C. McDowell and J. F. Kendrick, to bring this about. The testing program soon developed into a nation-wide herd improvement effort.

The departmental dairy workers, in cooperation with the state specialists and the American Dairy Science Association, assumed the responsibility of a coordinating agency for the program. The Division, and later the Bureau, served as a central repository for the data that were produced and sent to it from all the co-

operating states. Annual summaries were made of these data and the results were made available to the public. The data also were used by researchers to investigate trends and progress in average production of association cows and herds and to develop new information, procedures, and techniques to advance the testing program and to improve dairy farming generally.

After 50 years the testing association has grown to where on January 1, 1955, there were 2,288 associations with 41,240 herds consisting of 1,333,866 cows on the standard plan of testing. This represents about 5½% of the milk cow population.

As early as 1916, reference was made in a Division publication to investigations on using cow-testing association records to compare the production of daughters and their dams for the purpose of indicating the transmitting ability of bulls. In the following years the Division, and later the Bureau, began making daughter and dam comparisons for proving bulls and issuing listings of sire provings. In the early thirties, as a result of extensive study and the adoption of modern calculating machines, plans were begun to develop a nation-wide cooperative sire-proving program. By this time suitable forms and a system of ear tagging cows for identification purposes had been developed so that a complete file of all production records sent in to the Bureau could be kept for use in developing sire provings. A nation-wide cooperative sire-proving program was initiated in 1937. That year the publishing of an annual DHIA proved-sire list was begun. More than 50,000 sires have been proved in this program to date.

Dairy cattle breeding research. The first dairy cattle breeding research in the Department was begun by T. E. Woodward at Beltsville in 1912, at which time 16 cows of mixed breeding, 1 purebred Holstein bull, and 1 Guernsey bull were purchased. Two inbred lines were developed, one from the Holstein sire and his male descendants, and one from the Guernsey sire. The purpose of the research at that time was to see whether a small herd owner might safely breed a bull back to his daughters, and thus avoid having to replace him with another bull. The results published in 1933 and in 1946 indicated that if a bull carried no lethal factors or factors for malformed calves he could be safely bred back to his daughters but that generally farmers should not practice inbreeding of their dairy cattle. The possible hazards from intensive inbreeding were pointed out.

In 1917, a more comprehensive breeding experiment was begun by R. R. Graves and later continued by M. H. Fohrman. This work was to involve a large number of animals over a long period of years, which would be necessary in a breeding experiment of this nature with large animals. Both the Holstein-Friesian and Jersey breeds were used in these investigations. There were several phases to these breeding investigations. Because of the early interest in the proved sire, this research was planned to demonstrate the value of the continuous use of meritoriously proved sires for improving the production of the female herd. In addition, inbreeding, linebreeding, and outcrossing systems of breeding were investigated. With the Jerseys, the then popular family breeding system, a form of linebreeding, also was tested. These experiments were the result of a long-felt need for greater knowledge of the fundamental principles of breeding dairy cattle. When these projects were laid out, the planners recognized the important influence that changing environmental conditions might have on production records, so from the beginning all reasonable efforts were made to maintain the same feeding and management conditions for each generation of animals on the experiments.

As the several dairy field station herds were established, they were utilized in an extension of the Beltsville breeding investigations, particularly those relating to the proved sire. In this respect the Beltsville proved sire breeding investigations were replicated in one form or another at each of the field stations.

Progress reports of this breeding research indicate that the continuous use of meritoriously proved sires generation after generation, either with natural or artificial breeding, produced a significant increase in the production ability of the experimental herds of Holsteins and Jerseys and that the variability of production among the daughters of the proved sires used was reduced with succeeding generations. Greater production performance was obtained from outcrossing than from linebreeding or inbreeding. Family breeding in the Jerseys did not yield superior results to outcrossing.

Recognizing that the supply of meritoriously proved sires was very limited, the Bureau started a program of lending to farmers and farmer groups sons of proved sires used in the projects. The loans were made with the agreement that the farmers test their cows and furnish the investigators with production data with which to measure the transmitting ability of these bulls. To date about 1,200 young bulls from Beltsville and the field stations have been on loan to farmers, cooperative bull associations, and artificial breeding associations. More than three-fourths of these bulls have been proved and over three-fourths of the bulls proved sired daughters that on the average were better producers than the daughters' dams when tested under farm conditions.

In 1935 when the value of the production-proved sire was being rather conclusively demonstrated and when the DHIA testing and sire-proving work was well under way, the Bureau, in cooperation with the state colleges, made a comprehensive germ plasm survey of the progress that had been made in college and farmers'

herds toward improving the quality of the dairy cattle. This survey analyzed 1,068 herds representing seven breeds of dairy cattle in 43 states. The results of this study were reported in the 1936 Yearbook of Agriculture and tended to inventory the position and progress that had been made in these herds that had been on a testing program for a number of years.

In 1936 the Bureau imported a herd of 20 heifers and two bulls of the Red Dane breed from Denmark. The purpose was to test the value of this breed of dairy cattle, which had reached such prominence in Denmark, under conditions in the United States. This herd has been maintained and increased through its offspring. At Beltsville it was found that this breed performed favorably but no better than our existing breeds. Through cooperative arrangement with the Michigan State College bulls from this herd were made available to farmers in several localities in Michigan for use in their herds and for proving. This resulted in a group of farmers in that state developing an interest in the breed to the extent that they have organized a breed registry program known as the American Red Danish Cattle Breeders Association.

In 1947 the Beltsville Red Dane herd was moved to Indiana, where it is used in a cooperative breeding research project with the Indiana Agricultural Experiment Station.

As a result of interest in crossbreeding and the development of hybrids in plant and animal species other than dairy cattle, M. H. Fohrman in 1939 initiated investigations to develop information on the value of crossbreeding dairy cattle for commercial purposes. In this research three breeds were used, Holstein, Jersey, and Red Dane. A breed rotation pattern was used so that each project animal was bred to a purebred, meritoriously proved bull. The results of these investigations, published in 1954, suggested that commercial dairymen who are not interested in a particular breed of cattle could enhance the producing ability of their cows by breeding them to the best proved bull available, regardless of the breed.

In 1946 the Bureau's breeding research was significantly enlarged by developing projects in cooperation with 10 different state stations. In this research various projects on inbreeding, linebreeding, outcrossing, crossbreeding, relation of breeding to composition of milk, and related problems are under study.

Breeding research was undertaken to see what could be done to develop strains of dairy cattle that are better adapted to the more severe climatic conditions in the South. In 1946 two heifers and two bulls of the Red Sindhi breed of Brahmans were introduced from India. These animals formed a foundation for crossbreeding experiments with the Sindhi, Jersey, Holstein, and Brown Swiss. This work is in progress at Beltsville, Jeanerette, La., and at three southern state experiment stations. As a part of the breeding research, physiological and climatological investigations are in progress to study the reaction of the animal to its climatic surroundings and the manner in which it adapts itself to high temperatures and humidity. This basic work involved the development of methods for measuring such animal reactions as body temperature, skin temperature, heat production and dissipation, and moisture loss. This research will enable scientists to more accurately measure climatic stress and the adaptability of animals to hot climates.

Growth, conformation, and anatomy in relation to producing ability. From the beginning of dairy cattle research, Department workers realized the need for information on the rate of growth and development of animals throughout their life. Systematic programs for recording weights and other measurements of animals in the several herds were used. Growth standards have been developed and published from these data. The most recent standards for Holstein and Jersey cows were issued in 1955.

In 1922 W. W. Swett started taking detailed measurements of the external form of cattle at specified ages for the purpose of determining if ways could be found from such data to identify superior or inferior producing animals. The need for culling inferior animals always has been great, and if a simple method could be developed to guide the farmer in selecting such animals at early ages it would greatly reduce the cost of raising herd replacements. Measurements of the size and weight of internal organs of animals killed after their period of usefulness were obtained so that correlations could be made with producing ability. Measurements were also made of the size, shape, capacity, structure, and attachment of the cow's udder.

This kind of research was undertaken in an effort to determine the most desirable size and shape of a cow for the greatest and most efficient performance. From time to time summaries have been published of such findings as the relation of birth weight and weight of calf at various ages to mature weight and production; the embryonic development of the fetus; the early identification of freemartins; the relation of size of cow to production; the relation of size of various glands, such as the thyroid, to production; the knowledge that milk secretion is a continuous process; the structure of the secretory tissue and the circulatory system of the udder; and the rate of release of milk from the udder.

As a part of these studies regular periodic measurements were made of the growth and development of the udder of the growing calf. This, together with postmortem studies of the udders of calves, led to a new understanding of the growth and development of the udder. Measurements taken of the udders of many calves revealed considerable variation in the size at particular ages. Bureau calves were systematically graded on the degree of udder devel-

opment, and these grades later were related to the milk yield of the animal as a cow. Correlations indicated significant relationships, and this led to the idea that a system of grading calves could be developed which would, with some accuracy, identify the future inferior producers, by means of udder palpation, when they are 4 to 6 months of age. Such a system has been developed and was made available in a Department bulletin in 1955. The palpation system presently is being tested out under field conditions, and, if it proves as good in the field as it has at the Beltsville station, farmers will have at their disposal a more accurate method than they now have to cull the prospective low producers from their herds before much cost has gone into their raising.

Reproduction and lactation. Problems relating to efficient reproduction and lactation have long occupied the attention of Departmental dairy scientists. Shortly after the Bureau was organized in 1924 studies were begun by F. W. Miller at Beltsville on factors affecting the breeding efficiency in cows and bulls. Studies were made of the normal and abnormal male and female reproductive tracts. In 1930 the first bovine tubal ovum ever observed was recovered from a cow at Beltsville. This was followed by culture studies of bovine and rabbit ova. By 1935 fertilized rabbit ova were recovered and the early embryonic development was observed. This, together with a picture story of fertilization, gestation, and parturition, was portrayed by cinematographic and motion picture techniques.

Studies on the collecting and on the composition, storage, and keeping quality of semen were begun in 1930. Studies on the rate of semen movement in the female genital tract were reported in 1933, and in 1935 a technique for collecting semen from bulls not able to serve normally was described. At that time shipments of semen were made from Beltsville to field stations for artificial insemination but without success.

About 1935 physiological studies were started by S. R. Hall on the hormones involved in reproduction and lactation, including the pituitary, gonadotropic and lactogenic substances. Excreta of bulls and cows were studied for hormone-like substances. These researches contributed to the early understanding of the role of hormones in reproduction and lactation.

In 1941 studies were begun on the influence of nutrition on the reproductive performance of bulls, and a report appeared in 1946 on the effect of vitamin A deficiency on the development and reproductive performance of bulls.

As purified hormone materials became available, work was taken up by J. F. Sykes in 1945 on the relation of prolactin and other lactogenic hormones to the development and function of the mammary gland. Basic studies were begun on developing improved chemical and biological methods for estimating the content of certain hormones in blood and tissue. Histochemical studies also were begun on the physiological activity of the female reproductive organs.

Since 1946 an expanded research program, in cooperation with five different state experiment stations, has been in progress to develop new information on nutritional and physiological causes of infertility in cows and bulls. This physiological research has contributed, and will continue to contribute, to improving the reproduction and lactation efficiency of dairy cattle.

Milk secretion. Some of the earliest work of the Dairy Division concerned itself with milk secretion. Cooperative work with the Missouri Agricultural Experiment Station between 1905 and 1912 dealt with various aspects of milk secretion, such as the influence of breed, feed, and individuality on the yield and composition of milk. Reports by Eckles and Shaw and others give their findings in several of the early Division publications. These include "Influence of Stage of Lactation on the Composition and Properties of Milk"; "Influence of Breed and Individuality on Composition and Properties of Milk"; "Variations in the Composition and Properties of Milk of Individual Cows"; and "Estimation of Total Solids in Milk by Formula."

Later, in 1915, E. B. Meigs was employed by the Division to study more precisely the actual mechanism of milk secretion. This work was done at Beltsville and concerned itself more with the chemical constituents in feed and blood as precursors of milk constituents. The minerals, calcium and phosphorus, in blood and milk were studied, as were the various amino acid constituents. The work on amino acids led to a better understanding of the precursors of milk protein. Reports by E. B. Meigs and C. A. Cary on the "Influence of Calcium and Phosphorus on Yield of Milk; The Relation Between Diet, Composition of Blood and Secretion of Milk; Calcium and Phosphorus Metabolism in Dairy Cows; The Effect of Water in the Ration on the Composition of Milk"; etc., describe these researches.

Later work on frequency, regularity, and rapidity of milking, the influence of machine and hand milking, and related studies have contributed knowledge to this important subject.

Nutritional requirements of dairy cattle. It was early recognized that to be able to feed cows efficiently one must have a good knowledge of the requirements for the different nutrients for growth, reproduction, and lactation. Work on nutritional requirements began by cooperative studies by H. P. Armsby at the Pennsylvania Agricultural Experiment Station and continued from 1915 to 1922. This work concerned itself with the energy requirements of cattle and a determination of the energy value of feeds. Work begun at Beltsville in

1915 and continuing until about 1945 dealt with the calcium requirements of calves and cows for normal growth, reproduction, and lactation. These researches involved long-time studies with animals during growth and throughout several lactations and have contributed much to our present-day knowledge of the calcium requirements of dairy cattle.

The protein requirements for milk production came under investigation in the late 1920's. Much of this research was directed towards both the level and the amino acid composition of the protein required. Considerable chemical work was done on developing methods for determining amino acids in proteins of feed and milk and in testing out feeds low in certain amino acids. Later, in 1945, a new series of experiments was initiated to study the level of protein. Cows were carried through several lactations on protein levels of 70, 100, and 120% of the Morrison standards. Cows receiving the low level performed as well as those receiving the recommended or more than the recommended amount. This work was pertinent to the then limited protein supply caused by war conditions.

Shortly after vitamin A was discovered, work was begun on determining the needs of this vitamin for the calf and the cow. This was prompted by the fact that some of the experimental animals on calcium requirement and hay-quality feeding experiments were found to be affected with vitamin A deficiency. This was evidenced by failure of the cow to deliver a normal calf at parturition or by giving birth to blind and weak calves. Night blindness in some of these cows also occurred. Systematic studies on the requirements for carotene, the natural source of vitamin A for the cow, resulted in information on the amount of carotene cows need for normal health and reproduction. Likewise, the amount of carotene or vitamin A needed by the calf for normal growth was studied, and information from Bureau laboratories added to the knowledge of this subject. Considerable information was also gained regarding the symptoms and pathology of vitamin A deficiency.

The nutritional requirements of calves for protein, energy, trace minerals, vitamins D and E, and the water-soluble vitamins have been, or presently are being, studied in order to gain a clearer knowledge of the need for these nutrients in the growth of the calf. Much of the current work is being done with synthetic-type diets that have been perfected to a rather high degree of proficiency.

Early work developed information on raising calves with no whole milk and a minimum of skimmilk. These findings were especially important during World War II when milk was in short supply.

Pasture research. Research on more efficient production, management, and utilization of pasture always has been an important part of the experimental program. Improvements in the utilization of this important low-cost feed crop offered one of the best ways of lowering the cost and increasing the efficiency of milk production. Pasture studies have been carried on at Beltsville and at all the field stations. The evaluation of new pasture crops and of crop combinations developed and proposed by agronomy coworkers has been made in each of the regions where field stations are located. Important information has been developed regarding the value of rotational grazing, pasture fertilization, supplemental irrigation; the value of permanent, rotation, and supplementary pasture; the importance of legumes in the pasture mixture; daily rotational grazing; green feeding, etc. Also, important contributions have been made to the development of techniques for experimentally measuring the yield of pasture with dairy cows.

Research on harvesting and utilization of forage. Investigations on harvested forage always have had an important place in the feeding and management research at Beltsville and at each of the field stations. One of the first projects at the Beltsville station was devoted to the making of silage. The first work was on factors affecting the losses, quality, and feeding value of corn silage. Studies were carried on at various times with upright, trench, snow fence, stack, and bunk silos. Extensive feeding experiments were conducted with corn silage as the principal or the entire forage ration. Weights per cubic foot of different kinds of silages stored in silos of different sizes, kinds, and shapes have been determined in order to establish silo capacities.

Early in the 1920's considerable attention was given to making silage from grasses, legumes, and grass-legume mixtures. After extensive tests with various additives, etc., T. E. Woodward and J. B. Shepherd developed and recommended the now popular wilting method of making grass silage. In this work many feeding tests were conducted to evaluate the various experimental silages produced.

In spite of all the work that has been done on making grass silage and the prominence that grass silage is taking on dairy farms at present, a large amount of research is still being done on this problem. Much of the current work is of a basic chemical and bacteriological nature and is designed to give fundamental information to guide practical grass-silage-making procedures.

In the same manner, research on hay as feed for dairy cattle has been a major activity. The relation of quality to feeding value, the conditions that make for good quality hay, the losses due to harvesting and storage, method of curing, etc., have been subjects of investigation.

One of the significant researches in forage was that done by the Bureau under the leader-

ship of J. B. Shepherd and in cooperation with other Departmental Bureaus on the comparative efficiency of four different ways of harvesting and preserving forage. This work was reported in 1954. The results of this study have focused new attention on the need for improving the quality of roughage and on the production of grass silage.

Bureau workers at Beltsville and the field stations have conducted and reported investigations on the feeding of all-forage rations to dairy cattle. The results point up the important contribution that forage can play in the economical production of milk and demonstrated that good cows fed all-forage rations will produce 60 to 70% as much milk as they will on rations including with the forage a normal amount of concentrates. Other work in cooperation with 10 state experiment stations and the Bureau of Agricultural Economics dealt with the feed input–milk output relation in feeding dairy cows. Research is currently in progress on raising herd replacements largely on forage rations.

When it was learned that carotene in the feed was the natural source of vitamin A for the cow, much work was done on determining the carotene content of feeds, especially forages, and on measuring the influence of various factors affecting the carotene content of feeds. The rate of loss of carotene in hay and silage was determined, and the fact that silage making is a good way to preserve carotene for feeding was established.

Another more recent phase of the forage research is the improvement and development of new techniques for evaluating the nutritional value of forage. Recent research on this phase involves the improvement in the procedures for the chemical determination of the nutritive constituents in feeds and improvement and simplification of the methods for determining the digestibility of feeds. Research on determining the net energy value of forages is being revived. Work in this field was originally started by Armsby but fell by the wayside in the early 1920's.

Another phase of forage research is the role of rumen bacteria in the utilization of forage nutrients. Systematic studies of the identification of the rumen microorganisms, their nutritional requirements, and their role in feed utilization by the cow are in progress at the present time.

Research on feed supplements. The value of grain and of grain-and-seed by-products as feed for dairy cattle has been given much attention, especially in the earlier years of the Department's dairy research. The value of grain mixes as supplements to forage and pasture of different qualities, the comparative value of single grains or complex grain mixtures as supplements, the value of southern by-product mixes, and related problems have been investigated. During the years 1945 to 1954 extensive investigations by L. A. Moore and J. W. Thomas of the value of feeding thyroprotein to dairy cows have contributed greatly to our knowledge of this subject. Antibiotics for calves and stilbestrol and other hormone-like materials for cows have been or are being investigated with respect to feeding dairy cattle.

Nutritional value of milk. Shortly after the Bureau of Dairy Industry was established, a unit was set up to study the nutritional value of milk, especially as it is affected by the nutrition of the cow. Some of the first work dealt with the vitamin A content of milk and butter. Research showed how the vitamin A value of milk and butter varied with the carotene received in the feed by the cow and that the cow was very wasteful in the utilization of carotene. It also brought out the importance of preparing forage for winter feeding in such a way that it would have a good carotene content and thus insure a milk supply of high vitamin A value. It also showed the significance of the cow's body reserve of carotene in relation to the vitamin A value of milk.

In 1941, in cooperation with 21 state colleges, a national survey of the vitamin A content of the nation's butter supply was initiated. This was a war-time project and the results that were published in 1945 and 1947 received much attention.

In 1937 this work on milk nutrients revealed the existence of an unidentified nutrient in milk. During succeeding years, studies were made of the physiological effects of the nutrient and its chemical and physical properties. Shortly after the discovery of vitamin B_{12}, Bureau scientists found it to be identical with the nutrient with which they were working. Further research has shown that the B_{12} content of milk is not dependent on the B_{12} in the feed of the cow and that milk and dairy products are good sources of this vitamin.

Research on the nutritional value of butter and butterfat as compared to that of certain vegetable fats and oils was taken up in 1942. Extensive studies have failed to show any superior nutritive value for butter or butterfat when fed in normal amounts with an otherwise nutritionally complete diet.

Miscellaneous investigations. A number of different types of management investigations have been included in the research program from time to time. A study of mastitis, especially the kinds of bacteria causing mastitis, management methods of control, and the treatment of mastitis has been carried on during the past 20 years. The Hotis test for detection of certain mastitic organisms was developed in 1936. The efficiency of various sulfa drugs and antibiotics in treating mastitis infections has been studied and reported on. The effect of the amount of vacuum of milking machines on the incidence of mastitis was reported.

Various methods of housing cattle, including loose housing, have been investigated, especially at the field stations. The first milking parlor was installed at Beltsville in 1928, and much of the pioneer work on this type of milking installation was done there. The effect of water in the ration on the yield and composition of milk received attention. With the introduction of new pesticides for the control of insects, studies were made of the effect of fly sprays on cows and of the incidence of spray residues in milk caused by contamination of the feeds receiving the treatment before harvesting.

Disease research. For more than half a century veterinarians of the Bureau of Animal Industry and, more recently, of the Animal Disease and Parasite Research Branch have carried on a great amount of research on diseases and parasites affecting dairy cattle and other farm livestock. The causes of many diseases have been identified, and the development of methods for their control and eradication is the result of this research. The development of vaccines that build immunity to certain diseases has protected great numbers of cattle.

Department entomologists also have made great contributions to the control of external insects and parasites affecting dairy cattle. Development of new chemical pesticides, followed by their practical use, is doing much to protect the farmers' cows from the ravages of these pests.

Research Roads Ahead

During the life of the American Dairy Science Association, an organization in which most of the Department dairy production research workers have enjoyed a membership, these men have contributed significantly to the knowledge now being used by farmers to improve their methods and practices. Much progress has been made, as indicated by the fact that milk production per cow has increased from 2,400 lb. in 1895 to over 5,500 lb. in 1955. The quality of the milk produced has been greatly improved. This has been accomplished largely as the result of application of knowledge gained through research, which has made possible better breeding, feeding, and management practices.

But the job is far from finished. The average milk yield per cow is still too low. In the future faster progress must be made in order for the dairy farmer to hold or improve his relative position in American agriculture. Much more research is needed to enable him to speed up the rate of improvement in the efficiency of milk production.

Past research endeavor has dealt for the most part with the easy problems. The difficult ones still lie ahead. Because of inadequate techniques and equipment when some of the past research was done, it needs to be done over with better equipment and methods.

More attention needs to be directed to basic research because it is only through this endeavor that "break through" to the unknown can come that will advance our knowledge resulting from both basic and applied research.

In the future the dairy farmer's opportunity lies in improving the efficiency of milk production, the efficiency of transforming energy and other nutrients in crops into milk nutrients. He must develop cows that are more adaptable and efficient in this conversion. More efficient cows must come through breeding, and research must show how this can be done.

Dairy farmers must greatly improve feed supplies and feeding practices to more efficiently furnish cows the necessary materials for the manufacture of milk in large amounts. Emphasis should be placed on better use of pasture and harvested forages, since these are low-cost feeds and are essential crops for good land use. Better criteria are needed to evaluate feeds. It is time to modernize the feed evaluation methods by shifting to net energy values. Research is needed to remove this roadblock in the way to better feeding.

More complete knowledge of the role of rumen microorganisms in the utilization of feed nutrients by the cow will enable the farmer to take advantage of their aid in improving the efficiency of milk production.

Finally, we must learn how to greatly improve the management of dairy cattle so that they can be cared for with greater comfort and with a minimum of labor and investment in housing. The final research objective is to produce the needed information to enable the dairy farmer to obtain the greatest output of milk per cow, per unit of feed input, per acre of land farmed, and per unit of labor expended. This is the objective to which the Department dairy production research workers are dedicated.