EFFECT OF HIGH AND LOW PROTEIN CONTENT ON THE DIGESTIBILITY AND METABOLISM OF DAIRY RATIONS

OHIO
Agricultural Experiment Station

WOOSTER, OHIO, U. S. A., MAY, 1924

BULLETIN 376

OHIO AGRICULTURAL EXPERIMENT STATION

STATION STAFF

C. G. WILLIAMS, *Director*

ADMINISTRATION
THE DIRECTOR, *Chief*
WILLIAM H. KRAMER, *Bursar*
W. K. GREENBANK, *Editor*
MARGARET WILLIAMS, A. B., *Librarian*

AGRONOMY
THE DIRECTOR, *Chief*
J. B. PARK, Ph. D., *Associate*[1]
L. E. THATCHER, Ph. G., *Associate*
F. A. WELTON, M. S., *Associate*
C. E. DIKE, B. S., *Assistant*
V. H. MORRIS, M. A., *Assistant*
C. A. PATTON, *Assistant*
G. H. STRINGFIELD, B. S. A., *Assistant*

ANIMAL INDUSTRY
G. BOHSTEDT, M. S., *Chief*
B. H. EDGINGTON, D. V. M., *Associate*
D. C. KENNARD, B. S., *Associate*
D. S. BELL, B. S., *Assistant*
R. M. BETHKE, Ph. D., *Assistant*
C. H. HUNT, A. M., *Assistant*
W. L. ROBISON, M. S., *Assistant*
P. S. WHITE, B. S., *Assistant*
A. R. WINTER, M. S., *Assistant*

BOTANY
H. C. YOUNG, Ph. D., *Chief*
ROY C. THOMAS, M. A., *Associate*
R. B. WILCOX, M. S., *Associate*[2]
FREDA DETMERS, Ph. D., *Assistant*
TRUE HOUSER, B. S., *Asst.*, (Germantown)
PAUL E. TILFORD, B. S., *Assistant*
W. J. YOUNG, M. S., *Assistant*

CHEMISTRY
J. W. AMES, M. S., *Chief*
MABEL CORBOULD, B. S., *Assistant*
C. J. SCHOLLENBERGER, *Assistant*
WM. A. SIMKINS, B. S., *Assistant*
RAUB H. SIMON, A. M., *Assistant*

CLIMATOLOGY
W. H. ALEXANDER, *Chief* (Columbus)[2]
C. A. PATTON, *Observer*

DAIRYING
C. C. HAYDEN, M. S. *Chief*
C. F. MONROE, M. S., *Assistant*
A. E. PERKINS, M. S., *Assistant*

ENTOMOLOGY
H. A. GOSSARD, M. S., *Chief*
J. S. HOUSER, M. S. A., *Associate*
HERBERT OSBORN, D. Sc., *Associate*[1]
C. R. CUTRIGHT, M. S., *Assistant*
L. L. HUBER, Ph. D., *Assistant*
A. E. MILLER, M. S., *Assistant*
C. R. NEISWANDER, M. S., *Assistant*

FORESTRY
EDMUND SECREST, B. S., *Asso. Dir., Chief*
O. A. ALDERMAN, M. F., *Assistant*
J. J. CRUMLEY, Ph. D., *Assistant*
F. W. DEAN, B. S., *Assistant*
B. E. LEETE, M. F., *Assistant*

HORTICULTURE
J. H. GOURLEY, M. S., *Chief*
W. J. GREEN, *Consulting Horticulturist*
F. H. BALLOU, *Associate*, (Newark)
JOHN BUSHNELL, M. S., *Assistant*
C. W. ELLENWOOD, *Assistant*
F. S. HOWLETT, *Assistant*
I. P. LEWIS, B. S., *Assistant* (Marietta)
ROY MAGRUDER, B. S., *Assistant*
W. F. ROFKAR, B. S., *Assistant*

SOILS
CHAS. E. THORNE, M. S. A., *Chief*
J. W. AMES, M. S., *Asso. in soil chemistry*
F. E. BEAR, Ph. D., *Associate*[1]
L. D. BAVER, B. S., *Assistant*
A. BONAZZI, B. Agr., *Assistant*
G. W. CONREY, Ph. D., *Assistant*[1]
I. H. CURIE, B. S., *Assistant*
T. C. GREEN, *Assistant*

FARM MANAGEMENT
C. W. MONTGOMERY, *Chief*
L. B. NETTLETON, *Assistant*

DISTRICT EXPERIMENT FARMS

Northeastern Test-Farm, Strongsville
J. T. WILSON, *Foreman*

Southwestern Test-Farm, Germantown
HENRY M. WACHTER, *Manager*

Southeastern Test-Farm, Carpenter
S. C. HARTMAN, M. S., *Supt.* Marietta

COUNTY EXPERIMENT FARMS

Miami Co. Experiment Farm, Troy
Madison Co. Experiment Farm, London
H. W. ROGERS, *Supt.*, London

Paulding Co. Experiment Farm, Paulding
H. R. HOYT, *Supt.*, Wooster

Clermont Co. Experiment Farm, Owensville
Hamilton Co. Experiment Farm,
W. E. WEAVER, *Supt.*, Mt. Healthy

Washington Co. Experiment Farm, Fleming
Washington Co. Truck Experiment Farm, Marietta
S. C. HARTMAN, M. S., *Supt.*, Marietta

Mahoning Co. Experiment Farm, Canfield
Trumbull Co. Experiment Farm, Cortland
A. W. NETTLETON, B. S., *Supt.* Canfield

Belmont Co. Experiment Farm, St. Clairsville
G. M. DEGROFT, *Manager*, St. Clairsville

STATE FORESTS

Athens, Lawrence, Scioto, Ross, and Pike Counties.

---

[1]The College of Agriculture, Ohio State University, Columbus, cooperating.
[2]The U. S. Department of Agriculture, cooperating.

CONTENTS

This page intentionally blank.

BULLETIN

OF THE

Ohio Agricultural Experiment Station

NUMBER 376 MAY, 1924

EFFECT OF HIGH AND LOW PROTEIN CONTENT ON THE DIGESTIBILITY AND METABOLISM OF DAIRY RATIONS

A. E. PERKINS AND C. F. MONROE

Investigations regarding the reaction displayed by dairy cows toward the continuous use of rations decidedly high and of others decidedly low in protein content, have been in progress at the Ohio Experiment Station since 1911. More intimate studies of shorter duration have been conducted as to the use the animals made of the feed supplied. In view of results reported by other investigators touching this phase of the problem, it seems desirable to present the results obtained at this Station, at the present time and in advance of a detailed report on the entire subject.

PART I

ORGANIC CONSTITUENTS

LITERATURE

Tables summarizing the results of thousands of investigations regarding the digestibility of various feeds by different classes of animals have been published. In America those compiled by Henry and Morrison (1) are in most common use. References thruout this paper to "Average digestion coefficients" refer to the tables as there presented.

In reviewing work by Wolff, Kuhn, Lehmann, Kellner, Pfeiffer, and others regarding the effect on the digestibility of a basal ration of the addition of protein or of carbohydrates, Armsby (2) concludes that the presence of an excess of carbohydrates such as would be present in a wide ration, tends to lower the apparent digestibility of the ration, and that the addition of an excess of protein such as would be present in a narrow ration, while having little effect on the apparent digestibility of protein, has a stimulating effect on the digestibility of the carbohydrates, particularly the crude fiber.

Armsby (3) also reviews the work of Kellner; of Mumford, Grindley, Hall, and Emmett; and of Armsby and Fries, showing a decrease of digestibility of each ingredient of the ration attending the liberal feeding of cattle (steers in most cases), compared with the digestibility observed on maintenance or with less liberal feeding.

Eckles (4) studied the digestibility of the same ration except only as to amount, on two cows, when near maximum milk production and again when practically at maintenance. The digestion coefficients for the entire ration observed with each of these cows at the high feed and production level were considerably lower than calculated from average digestion coefficients, altho those observed under maintenance conditions were somewhat greater than those calculated from the same average coefficients. As a matter of convenience in the collection of samples and interpretation of results, practically all of the digestion coefficients reported for ruminants have been conducted on castrated male animals at or near a condition of maintenance. In view of the observed differences between his results and those calculated from the average figures, Eckles recommends further studies on the digestibility of the rations supplied high producing cows.

Ellett and Holdaway (5) report the results of digestion experiments on cows which had been fed continuously on what they designate as "High protein" and "High energy" rations, respectively. Marked reductions in digestibility, averaging 23 percent below the average figures for all ingredients, were observed in the case of cows receiving the high energy ration. The extra protein in the other ration was digested and eliminated without apparent effect on the digestibility of the ration.

Ellett, Holdaway, and Harris have recently reported that the addition of protein to a basal ration fed to producing dairy cows increased the digestibility of the ration; while the addition of carbohydrate to a similar basal ration reduced the digestibility.

The possibilities suggested by this literature demanded a determination of the digestibility of the rations employed in our work. Accordingly, four cows—111 and 154 from the group receiving the wide ration, N. R. 1:9, and 146 and 192 from the group receiving the narrow ration, N. R. 1:4—were selected for this work. Numbers 111 and 154 are purebred and 146 and 192 high grade Holstein-Friesian cows. All are of better than average productive ability.

Each of these cows was reared from weaning on a ration of the same type as that supplied her during the first, or 1921, balance period, described later. The dams of these cows had likewise been restricted to rations of the same type. At the beginning of the next lactation period following the 1921 work, cow 111 was changed from the wide to the narrow ration, and cow 146, from the narrow to the wide ration.

Cows 154 and 192 were given rations of N. R. 1:11 and 1:2, respectively, at the beginning of their new lactation periods. These rations departed from normal in the same direction but were of more extreme character than those they had previously received.

A second balance experiment was conducted on the same animals in July and August, 1922.

The data regarding digestibility, nitrogen balance, water consumption, etc., derived from these eight balance periods, are the subject matter of Part I. Data regarding the balances of the more important mineral elements were also secured and are presented in Part II.

CONDITION OF THE ANIMALS

All the cows employed in this experiment were vigorous, young animals; No. 192, the youngest, was in her second lactation period and No. 111, the oldest, in her sixth, at the time of the 1921 work. Live weight fluctuations of 300-450 pounds during the year seemed to be the rule with these cows. Possibly there was a slight tendency for the cows on the wide ration to become a little thinner in flesh than those receiving the narrow ration but the difference was not marked. None of the cows ever reached a condition of emaciation.

At the time of the balance periods here reported the cows were past the period of maximum production but had not reached the period of rapid decline which usually occurs near the close of the lactation period. As shown in Table I, they were also at or near the condition of minimum live weight. Cow No. 192 suddenly went "off feed" and developed a case of cramps and diarrhea on the eighth day of the 1922 work. For this reason she was dropped from the balance experiment. The administration of a purgative and a short period of fasting brought about a prompt return to her usual condition without change in the ration. The data for this period are based on the samples collected during 7 days.

CONDUCT OF THE EXPERIMENT

The report of the Committee on Methods of Experimentation of the American Society of Animal Production (6) was freely consulted and the recommendations carried out wherever consistent with our conditions. Since the rations used in these balance experiments were identical with those already in use with the same animals, it was deemed unnecessary to prolong the period of preliminary feeding, hence the collection of samples was begun as soon as the animals and attendants had become accustomed to the routine of the experiment. All feed used during the balance periods was of good quality. Each ingredient was mixed, weighed separately, sacked, and sampled for chemical analysis, before beginning the experiment. The aim was to feed each animal as much of the prescribed ration as she would consume without waste, and the rations were in all cases completely consumed. The water was obtained from deep drilled wells and was supplied to the animals ad libitum, but the amounts supplied were accurately weighed. A composite sample for chemical analysis was prepared as the experiment progressed.

Two ounces of salt was supplied each animal daily. This was completely consumed.

The feeding, milking, and watering were each done twice daily, and in all respects an effort was made to adhere as closely as possible to the routine to which the animals had been accustomed.

At feeding time the animals were confined in rigid stanchions but at other times they were fastened only with tie chains which allowed considerable freedom of motion. The stalls during the first experiment were covered by several layers of burlap overlaid with rubber hall-matting; during the second experiment the rubber matting was replaced with heavy waterproofed canvas.

The animals were thoroly curried and washed before going into the experimental stalls and were curried once a day during the course of the experiment. The daily brushings and stall sweepings were weighed and saved for chemical analysis. The cows were weighed each morning after feeding and milking but before watering.

The excreta were collected in buckets of about three gallons capacity; two buckets, one each for urine and feces, being provided for each animal. The feces were promptly transferred to larger tightly-covered storage containers and the urine to 5-gallon glass bottles. At the end of 12 hours these containers were taken to a cold room and other storage containers substituted. Three sets of storage containers were provided for each animal.

No particular difficulty was encountered in the quantitative collection of the feces. The unwashed buckets were weighed at the close of each 24-hour interval, and the difference between this weight and that of the clean, dry bucket, which difference never exceeded a few grams, was added to the weight of the main sample. Small quantities of urine were lost occasionally, these were taken up with a damp sponge and their volume ascertained. This volume was added to the total observed volume for that day but the recovered urine, being more or less contaminated, was never added to the main sample.

At the end of each 24-hour interval, the feces were weighed, thoroly mixed, and a sample of about 2 kg. withdrawn and placed in a tightly covered receptacle; 5 c. c. of a 10 percent thymol in chloroform solution was added as a preservative, and the sample stored in a cold room. The urine was thoroly mixed, measured, and sampled, 5 c. c. of the thymol chloroform preservative being added to each sample of 2½-liters volume. The samples were then stored in the cold room.

The milk was weighed on sensitive scales, and the entire daily production carefully mixed and sampled. To the milk 40 percent formalin was added as a preservative at the rate of about 10 drops per liter of sample. The samples were also stored in the cold room and were agitated daily to prevent the formation of a layer of cream which could not be readily mixed with the remainder of the sample.

Composite samples were prepared from each of these materials, representing six periods of three days each in the 1921 work and three periods of four days each in the 1922 work. Careful account was taken of the variation in production from day to day in preparing the composite samples. An additional portion of the preservative as previously described was added to the composite sample, which was then stored in the cold room when not in actual use.

The cold room referred to above was maintained at a temperature approximately 45 degrees F. The composite samples of fresh feces, however, were stored in a room whose temperature maintained them in a frozen condition. In addition to the sample of feces preserved in the original condition as just described, 1 kg. portions of the composite sample were promptly reduced to an air-dry condition by drying in thin layers at about 50° C., after which they were allowed to stand at room temperature for 48 hours or longer, when they were weighed and finely ground. The analyses of feces reported in this publication were made on samples prepared in this way; because it was found that much more uniform and consistent results were thus secured than could be obtained from the samples in their fresh condition.

METHODS OF ANALYSIS

The methods of chemical analysis employed were essentially those recommended by the Association of Official Agricultural Chemists. Identical methods were employed for the determination of any given ingredient in feeds, milk, and excretions, except that the fat in milk was determined by the Babcock volumetric method, instead of by extraction with ether; and that the water and solid content of both milk and urine were determined by calculation from the specific gravity, rather than by drying at the temperature of boiling water.

The essential data regarding both sections of the experiment are presented in the tables (see appendix).

DISCUSSION OF RESULTS

In Table I will be found data regarding the live weight of the animals before, during, and after the balance periods. In addition to observations already based on this table, (Page 87) it will be observed that during the early periods there was in several cases an apparent decline in live weight, compared with the last weights previously taken; but that in these cases, the live weights during the late periods were practically on a par with those immediately preceding the experiment proper. This condition is attributed to a sudden decline in water consumption followed by a gradual return to normal, possibly due to changed conditions. This assumption is borne out both by the data regarding water consumption and those regarding the elimination of urine from day to day (these detailed figures are not presented). We therefore believe that our animals were in a condition of approximately constant live weight during these experiments.

In Tables II to IX, inclusive, will be found the essential data regarding the supply and composition of the feeds employed and like data regarding the feces collected during the balance periods; also the digestibilities as observed in these experiments and those calculated for the entire rations by using average figures for each feed.

Table XII brings these figures together and shows the differences between the calculated and observed digestibilities for the different nutrients of each ration.

It will be noted, that in every case the average apparent digestibility as observed was less than that calculated from the average coefficients: the smallest deviation of 0.7 percent being with the nitrogen-free extract of the narrow ration; and the greatest, 22.7 percent, with the ether extract of the wide ration. These figures confirm the observation of Eckles (4) that the relatively heavy feeding, which must accompany sustained liberal milk production, results in lowered digestibility, when compared with the average digestion coefficients which, for the most part, have been obtained from animals at or near the level of maintenance.

The average divergence of the observed from the calculated digestibilities, it will be noticed, was slightly greater thruout with the wide-ration group than with the cows receiving the narrow or high-protein ration. The differences, however, are not sufficient to constitute an agreement with the findings of Ellett and Holdaway (5), except for the single ingredient, ether extract. There were important variations, however, in the conditions of the experiments which may account for this seeming contradiction.

Our work was done when the cows were producing liberal quantities of milk and they could not be depended on to consume regularly and completely such large excesses of energy as reported by Ellett and Holdaway. One of the "high energy" cows on which their observations were based was near the close of her milking period, while the other had suffered emaciation and a marked decline in milk, conditions which favored the consumption of large excesses of feed over the accepted requirements.

It is our purpose to repeat this work with these animals during the late stages of lactation, when conditions prevailing in the work of Ellett and Holdaway can be more nearly duplicated. Observations made during the early part of the lactation period when it is often difficult or even impossible to induce a cow to eat sufficient food to meet the theoretical energy requirements, would likewise seem to be most desirable. Mumford, Grindley, Hall, and Emmett (9) conclude that in their work on steers on different planes of nutrition the increased crude fiber content of the heavy rations was chiefly responsible for the decreased digestibility observed with them. A study of Table IV with this in mind will show that in our experiment the wide rations, which showed lower digestibilities thruout (see Table XII), contained on the average less crude fiber than the narrow rations; so that crude-fiber content could not have been the controlling factor.

Table XI shows the average daily production of milk and its constituents, Table XII the average daily elimination of urine and constituents, and Table XIII records the nitrogen supplied by the water and that given off in brushings and stall sweepings.

Table XIV presents in balance form the income and outgo of nitrogen from the bodies of the animals. Only two small negative N. balances were obtained; and the larger of these occurred in the case of a cow which at the time was receiving a considerable excess of protein in her ration. We are unable to account in any way for this negative N. balance.

In Table XVII will be found a study of the consumption and elimination of water. It has frequently been stated that an excess of protein in the ration increases the total intake of water and the elimination of water in the urine; but definite figures seem to be lacking in most cases so far as dairy cows are concerned. The data in Table XVII will show that in this experiment the average daily consumption of total crude protein by the two groups of cows was 2.89 pounds and 5.75 pounds, respectively, for the wide and narrow rations; an average difference in protein consumption of nearly 3 pounds per day. The corresponding averages for water consumption were 140.7 and 154.5 pounds, a margin of 13.8 pounds per day for the narrow over the wide ration. The elimination of water in the urine averaged 28.8 pounds for the wide-ration cows, and 52 for the narrow-ration group; a difference of 23.2 pounds per day, showing that the increased intake of water which went with the narrow ration lacked 9.4 pounds per day of balancing the increased elimination of water in the urine. Altho the average dry matter content of the two groups of rations is very close, and no pertinent comparison as to the effect of dry matter can be obtained between them, a study of the behavior of the individual cows in the two successive periods shows some interesting comparisons.

With cow 111 the increase of the 1922 ration over that supplied in 1921 was 5.82 pounds dry matter, of which 3.33 pounds was protein. The increase in water consumption was 35.2 pounds, while the additional amount excreted in the urine was only 17 pounds. However, in the case of cow 146, an increase of 3.61 pounds in the dry-matter content of the ration accompanied by a decrease of 1.18 pounds in the protein content called for an increase of 8.6 pounds of water in the amount given off in the feces, and a decrease of 29.3 pounds of water in that voided in the urine—19.6 pounds more water was secreted in the milk daily in 1922 than in the previous year. With cow 154 an increase of 2.82 pounds of dry matter, containing only a very slight increase in protein, resulted in an increased water consumption of 8.5 pounds and an increase of 8 pounds in the amount given off in the urine. With cow 192, an increase of 3.54 pounds in the amount of protein and an apparent increase of 1.35 pounds in total dry matter, but an actual decrease of 2.19 pounds in non-protein dry matter, called for the consumption of 33 pounds more water, and caused the elimination of 42.3 pounds extra water in the urine, accompanied by a decrease of 1 pound in the water given off in the feces.

It seems clear that the consumption of rations high in protein calls for the consumption of somewhat more water than required by other rations containing a similar amount of dry matter but of lower protein content. The high-protein rations seem also to stimulate the elimination of water in the urine to an even greater extent than they increase the consumption of water. Additional non-protein dry matter in the ration likewise seems to call for the drinking of additional water, most of which appears to be eliminated in the feces. The results are complicated by so many factors that the establishment of exact quantitative relationships would seem well nigh impossible.

Ellett and Holdaway conclude that in their experiment the formation of milk fat from other sources than digested food fat was favored by the high protein ration. Table XVIII brings together the results afforded by our experiment tending to answer this question.

The average daily fat production was slightly greater during the narrow-ration periods. In each group the total food fat was less than the milk fat. The marked depression in digestibility observed with the ether extract of the wide ration reduced the amount of digested fat in the wide ration to approximately one-half that in the narrow ration. For this reason the amount of milk fat produced in excess of digested food fat was much greater with the wide or low-protein ration than with the rations high in protein, pointing to just the opposite conclusion from that reached by Ellett and Holdaway.

Ellett and Holdaway also show that their cows on the high-energy ration were able to maintain themselves on much smaller quantities of protein than called for in the accepted standards. The data afforded by our experiment touching this point are summarized in Table XIX.

It will be observed that in each of the experiments on cows receiving the low-protein rations, the digested protein less the protein actually produced in the milk was considerably less than the commonly accepted maintenance requirement. The animals, with one exception, were in positive N. balance, and the negative balance in this case was very small and accompanied by an apparent slight increase rather than by a decrease in live weight. We may therefore conclude that the conventional maintenance allowance of protein was more than sufficient in each of these cases to provide for actual maintenance, as well as to compensate for any incompleteness in availability of the digested protein either for maintenance, or for the formation of milk protein, at the rather liberal rate of production maintained in these experiments. The rations used in our experiment contained a wide variety of feeding stuffs. In view of the fact that proteins from restricted sources have often been found inadequate to support proper growth, we are unable to say that these statements would apply to rations compounded from a small number of ingredients. Armsby (8) also points out that the minimum protein requirement for maintenance has been observed to vary to a marked extent between different individuals and under different conditions. Most of our cows as well as those of Ellett and Holdaway had long been accustomed to a diet relatively low in protein, which, conceivably, may have enabled them to make more efficient use of the protein supplied them than is common. On the other hand, however, cow 146, in our 1922 work, fully equalled the performance of the other cows in this respect, altho she had been transferred from the narrow to the wide ration less than two months previously.

SUMMARY OF PART I

The results of eight digestion and nitrogen balance experiments are reported, four on cows receiving rations with large excesses of protein, and four on cows receiving rations decidedly deficient in protein, compared to commonly accepted standards.

The cows were all producing liberal quantities of milk, altho in nost cases they had passed the period of their maximum prouction. They were also at or near their minimum in live weight.

With each of the cows the observed digestibility of each gredient of the ration was lower than the digestibility as figured the use of average digestion coefficients.

The margin of difference between the observed and the calıted digestibilities was greater thruout for the wide or low-protein ration than for the narrow or high-protein ration. Except for one ingredient, the ether extract, however, the depressions of digestibility due to the wide ration were not nearly so great as those reported recently by other investigators.

Larger total quantities of water and more water per unit of live weight were regularly consumed by the cows receiving the high-protein rations; altho the average dry matter content of the two groups of rations was practically the same.

The elimination of water in the urine was stimulated by the high-protein rations to an even greater extent than the consumption of water.

The amount of non-protein dry matter in the ration is also shown to have an important influence on the amount of water consumed.

So many complications are involved that the increased consumption of water or elimination of urine can not be related quantitatively to either the amount of protein or of dry matter consumed.

Contrary to the results of Ellett and Holdaway, the amounts of milk fat produced in excess of the total available supply of digested food fat was much greater in our experiments with the wide ration than with the high-protein ration.

The cows on the wide ration are shown to have been, with one insignificant exception, maintaining positive nitrogen balance, uniform or slightly increasing live weight, and liberal milk production when the amount of digested protein, remaining after the deduction of the protein actually secreted into the milk, was considerably less than the conventional allowance for maintenance.

PART II

MINERALS

In connection with the work described in Part I, data were also secured on the balances of the four mineral elements, calcium, magnesium, phosphorus, and sulphur. These data should be of interest in view of the facts that other investigators have observed heavy losses of some of these elements from milking cows, when confined to winter rations, and that the cows used in this work had been limited to winter rations all their lives and were still producing liberally.

LITERATURE

Forbes and associates (12), in an extensive series of metabolism experiments, found that the ability of the cow to utilize the inorganic constituents of the ration is much more limited than her ability to utilize the organic constituents. Their results particularly emphasize a limited ability of the liberally milking cow to utilize the calcium and phosphorus of the ration. The calcium balances were always negative when the milk production exceeded ten pounds per day, while the phosphorus balances were usually so. Losses of these elements occurred regardless of an apparently sufficient supply of them in the rations, which included such roughages as clover and alfalfa hays. Larger losses of calcium were encountered during the feeding of timothy hay than during the feeding of clover and alfalfa hays.

Standing somewhat contradictory to these results are those of Hart, Steenbock, and Hoppert (13), who observed positive calcium and phosphorus balances on three liberally milking cows. In these experiments alfalfa hay that had been cured under caps was fed as roughage. Replacing this alfalfa hay by green alfalfa seemed to increase the retention of calcium and phosphorus. The suggestion is made that the process used in curing the hay was instrumental in preserving the "unknown factors affecting calcium assimilation". They state that this is "in harmony with previous observations that green plant tissue contains more than dried plant tissue of some substance favoring calcium assimilation".

These authors (14) have shown that milking goats are enabled to utilize more efficiently the calcium of the ration when the fresh green oat plant is fed in preference to oat straw; and that the curing of oat hay out of the direct sunlight aided in the retention of those qualities which assist calcium assimilation.

Later work by Hart, Steenbock, Hoppert, and Bethke (15) has shown liberally milking cows to be losing calcium and phosphorus. In this case, alfalfa hay cured by four days' exposure to the sun while in the windrow was fed. However, these losses were often slight and, as the authors state, "could no doubt be maintained for a very long time without serious results to the animal". When timothy hay was fed large losses of calcium and phosphorus were encountered. Adding steamed bone meal to the ration containing the timothy hay reduced these losses somewhat but did not make this ration on a par with that containing the alfalfa hay.

Meigs, Blatherwick, and Cary (16) conclude from the results of metabolism experiments that the disturbance to the cow resulting from the separate collection of urine and feces as practiced in the metabolism experiments may interfere with the assimilation of phosphorus and nitrogen and more especially calcium. They point out that large calcium losses from the bodies of cows as reported in the various balance experiments are not to be explained on the basis of a wasting of the bones; because the losses of calcium and phosphorus have not been in the same ratio as that in which these elements are found in the bones. Meigs (17) also points out the apparent impossibility of such large losses of calcium as reported by Forbes. He claims that if these losses had continued that the cows would have lost half the calcium from their bodies by the end of their lactation.

OBJECT

The object of the work herein reported was to determine the calcium, magnesium, phosphorus, and sulphur balances of cows on winter rations of high and low protein content.

EXPERIMENTAL

The experimental procedure has been set forth in Part I. The data and samples secured in that work were used for the determination of the mineral balances. There are, however, some additional facts which seem to be worthy of mention in this connection.

Cows.—The cows used in this work were four of the seven in the group to which mineral supplements were fed by Forbes, while conducting mineral palatability tests (11). The original cows of this group had been confined to winter rations since 1911 and the four used in this experiment had been confined to such feeding all their lives. They showed a special desire for the salt and steamed bone meal, the average daily consumption of this mixture exceeding 1 pound at first. Later a mineral supplement consisting of steamed bone meal, precipitated calcium carbonate, flowers of sulphur, and salt was fed to them. This mixture had been given for 8 months, ending 45 days prior to the beginning of the 1921 digestion trial. Since that time they have received no mineral supplement, except salt.

Feeds.—All feeds used in these tests were of excellent quality with the exception of the timothy hay in 1921, which had evidently been cut when quite mature. The heads had shattered badly. The clover hay fed in both experiments was of that year's crop. This hay was cured in the sun for two days and was then spread out on the barn floor and allowed to dry thoroly. However, it was in proper condition for storing in the mow when taken from the field. When fed, it was of choice quality and had retained its original color. This hay had not been thru the sweat of the mow.

The corn was of a yellow variety and was used in the rations in a finely ground condition.

The water supplied the cows for drinking purposes was obtained from deep wells, a different well being used each year. Water was given to the cows in such amounts as they would drink, but a strict account was kept of the quantity consumed. The water was sampled daily and a composite sample prepared to represent the composition of the water used during the experiment. This deep-well or natural water was used in preference to distilled water in order to maintain as nearly as possible the normal conditions under which these cows had been kept. In our opinion it is no more essential, in conducting a mineral balance experiment, to purify the water than it is to purify the feeds, provided, of course, the same care be taken in determining the intake of elements contained therein.

The following were the methods of analysis employed:

Nitrogen—Kjeldahl-Gunning-Arnold method, Official.

Calcium—McCrudden method, Journal of Biological Chemistry Vol. 10, 194, 1911. Titrating the calcium oxalate precipitate with potassium permanganate.

Magnesium—McCrudden method, Journal of Biological Chemistry Vol. 7, No. 2.

Phosphorus—Official gravimetric method. Digesting sample with nitric and fuming nitric acids in the presence of sulphuric acid.

Sulphur—Modified Benedict method. Journal American Chemical Society, Vol. 41, No. 10.

The data regarding the mineral content of each ingredient of the rations are shown in Tables XIX and XX. The data regarding the mineral content of the milk are shown in Table XXI. The average daily intake, outgo, and balance of each of the minerals studied for each cow and for each season are presented in Tables XXII to XXIX, inclusive.

No composite samples of urine or feces representing the entire balance periods were prepared; the figures showing average daily outgo thru these channels being obtained from the production and composition of these materials for each of the separate periods into which our experiment was divided. These detailed figures are omitted in the interest of brevity.

CALCIUM BALANCES

Of the eight calcium balances here reported, four are negative and four are positive. The four negative balances occurred with cows receiving the wide rations. These losses of calcium were less than one gram in each of three cases and in the fourth, the loss amounting to 3.6 grams daily, occurred with a milk production of 52 pounds per day. All of the narrow ration cows were found to be storing calcium. Three of these storages were approximately 4 grams each and the fourth 8 grams. The plan of our experiment has not been such as to permit a definite answer explaining the cause for this difference in calcium retention between the two groups of cows. But reasoning from the results derived from other experiments, we are able to offer a possible explanation.

Hart and associates (13) have shown the possibility of cows storing calcium when producing from 20 to 45 pounds of milk daily, when alfalfa hay which had been cured under caps was fed. When green alfalfa replaced the alfalfa hay, the storage of calcium was increased. These calcium storages, when alfalfa hay cured under caps was fed, seem to be contrary to later findings by the same authors (15), and also to the results of Forbes and associates (12). Hart and assocates (13) suggest that this difference in calcium assimilation has been due to the quality of the hay used. They ascribe to the alfalfa hay cured under caps some of the same powers influencing calcium assimilation as those proven to be present in the green alfalfa.

As previously mentioned, the clover hay used in both of our experiments was well-cured, fresh hay, having been cut about one week prior to the preliminary feeding. It had retained its original color to a remarkable degree and had not been subjected to over-curing in the sun. This hay was used in all the rations, but in much larger amounts in the narrow rations. In the light of the former work, just referred to, it may be reasoned that the storage of calcium by the narrow-ration cows was due to the larger amounts of clover hay received by them, ascribing to this hay the presence of some organic factor assisting calcium assimilation. We offer this merely as a suggestion. There are other points to be taken into consideration in this connection—namely, the larger amounts of calcium and phosphorus contained in the narrow rations and that this type of ration furnished the greater part of its calcium in a leguminous roughage, the quality of the hay not being considered. Our data do not show the cause of this difference in calcium retention. But the balances here determined show that the narrow rations favored a greater calcium assimilation than the wide rations; and that, in accordance with the work of Hart and associates (13), it is possible for liberally milking cows receiving winter rations to store calcium.

In general, the calcium assimilation in these experiments was found to be more favorable than was anticipated, judging from the results of similar experiments conducted by others. The following points may account for this difference:

a. **The cows.**—As previously mentioned, these cows had been on winter rations all their lives. Consequently, they had been deprived of the "fresh-grass vitamin", which is supposed to aid in building up of large mineral reserves (18). We believe, therefore, that their status in regard to mineral reserves was different from that of the cows used in other experiments of similar nature. As a matter of fact, we are convinced, after examining their milk records in the several lactation periods, that the assimilation of calcium by these cows must have been more favorable than most of the mineral metabolism experiments have shown; for if this had not been true, either the milk production would have been considerably less or the animals themselves would have come to disaster.

b. **Quality of the clover used.**—Hart (13) has proved satisfactorily, we think, that alfalfa hays differ in regard to their effect on calcium assimilation. The question arises in our minds as to what extent the clover hay used in our work has favored the assimilation of calcium.

c. **The use of beet pulp.**—Dried sugar-beet pulp is highly regarded as a feed for dairy cows, especially by feeders who are intent on securing maximum production. It is bulky, highly palatable, and seems to possess valuable conditioning qualities. It has a high calcium content. In the metabolism experiments here reported the wide-ration cows received approximately half of their calcium from the beet pulp. It is possible that the use of beet pulp in these rations may have been the factor responsible for the favorable calcium balances observed; however, we have no proof that such is the case. Indeed, corn silage, rather than beet pulp, has been the succulent feed supplied these cows for the greater part of the year; and this, of course, is of low calcium content. No significant differences in production or otherwise have been observed in changing from silage to beet pulp or vice versa.

d. **The use of natural water of a fairly high lime content.**—The primary purpose of this experiment was to determine as far as possible the use made of the rations. Since natural water was regularly supplied, it was also used during the metabolism experiments. While our results show marked differences from those of other experiments on various winter rations with which distilled water was used in place of natural water, we are not prepared to maintain that the difference in water supply was the chief cause of such difference in results; but it is mentioned as a point worthy of further study.

PHOSPHORUS BALANCES

In considering the balances for this element, it must be remembered that the work of Hart and associates (13) has shown that the phosphorus assimilation, like that of calcium, may be affected by the quality of the hay. Here again our use of fresh clover hay may have had some effect on the balances. However, the data for 1921 show that phosphorus was lost by all the cows, those fed on the narrow ration losing slightly more. These conditions were reversed in the experiment of 1922, where we find three of the four balances positive and the one negative balance of one-half gram, occurring with a high level of milk production. In 1922 the narrow-ration cows were storing phosphorus in amounts exceeding four grams, while the storage for the one wide-ration cow whose milk production permits a comparison, was less than one gram per day. Here, then, we have a slight indication that the narrow rations would permit a larger storage of phosphorus. We are at a loss to explain the difference in the phosphorus balances of the two years. It is possible that the previous feeding of mineral supplements, which ended 45 days prior to the 1921 work, may have had some bearing on this question.

SULPHUR BALANCES

The balances for this element in 1921 were all negative, while those for 1922 were all positive. The gain or loss of sulphur was never more than two grams per day. No marked difference is shown between the balances of this element for the cows fed on the different types of rations. The apparent storages for 1922 may almost reach a point of equilibrium if the losses of sulphur due to shedding of hair are taken into account.

MAGNESIUM BALANCES

Magnesium losses are shown in three of the eight balances; these have all been less than one gram per day and all have occurred with the storage of nitrogen. In one instance, the balance shows an exact equilibrium of intake and outgo; this also occurred with a storage of nitrogen. Of the four positive balances of magnesium, two occurred with nitrogen gains and two with nitrogen losses. There is little difference between the storages or losses of magnesium thru feeding the different type rations. The outgo of this element in the urine for each individual has seemingly been little affected by the ration.

NITROGEN BALANCES

In contrast to the extreme differences in the nitrogen intakes in the two types of rations, no marked effects are seen in the balances for this element. Six of the eight balances are positive, the average daily storage varying from 3 to 19 grams. Two losses are noted, one amounting to less than 1 gram, occurring with a low nitrogen intake, and the other approximately 5 grams, occurring with a high nitrogen intake.

SUMMARY OF PART II

Eight balances of calcium, magnesium, phosphorus, sulphur, and nitrogen are reported. Four of these balances were determined on cows receiving high protein rations, and four on cows receiving low protein rations.

The mineral content of the narrow rations was higher, especially in phosphorus and calcium.

All the cows receiving the high protein rations were found to be storing calcium, while those receiving the low protein rations were found to be losing this element. It is suggested that this difference in calcium storage may have been due to the larger amounts of clover hay contained in the high protein rations. The clover hay used was fresh hay that had not been subjected to an excessive amount of bleaching in direct sunlight. The data here presented show the possibility of calcium retention with liberal milk production, when winter rations are fed.

In the 1921 experiment, the phosphorus balances for the two groups of cows were somewhat similar, losses being noted in all cases. The results of the 1922 experiment indicate that the narrow rations, here used, would permit a greater phosphorus retention than the wide rations.

The magnesium, sulphur, and nitrogen balances of the cows fed the high protein rations show no marked differences from the corresponding balances of those receiving the low protein rations.

The calcium and phosphorus balances obtained in this experiment are much more favorable than those obtained by other workers under seemingly similar conditions.

The points at which the conditions of our experiment differed from the conditions described by others are enumerated and the probable effect of each is discussed.

REFERENCES

1. Henry, W. A., & Morrison, F. B., Feeds and Feeding, Madison, Wisconsin, 16th Edition, Page 647.

2. Armsby, Henry Prentiss, The Nutrition of Farm Animals, The Macmillan Co., New York, Pages 616-622.

3. Ditto, Pages 613-616.

4. Eckles, C. H., Digestion Trials with Two Jersey Cows on Full Ration and on Maintenance, Missouri Agricultural Experiment Station, Research Bulletin No. 4.

5. Ellett, W. B. and Holdaway, C. W., The Effects of High Protein and High Energy Rations in Feeding Dairy Cows, Virginia Agricultural Experiment Station, Technical Bul. Nos. 12 and 20.

6. American Society of Animal Production, Proceedings 1915, page 101.

7. Methods of Analyses, Association of Official Agricultural Chemists, Washington, D. C., 1921.

8. Armsby, Henry Prentiss, The Nutrition of Farm Animals, page 326, loc. cit.

9. Mumford, H. W. and Grindley, H. S., Hall, L. D., and Emmett, A. D., A Study of the Digestibility of Rations for Steers, Illinois Experiment Station, Bulletin 172.

10. Ellett, W. B., Holdaway, C. W., and Harrin, W. G., Feeding Standards for Milk Production. Virginia Agricultural Experiment Station, Technical Bulletin 23.

11. Forbes, E. B., Science, New Series, Vol. 52, 467, 1920 and Ohio Agr. Exp. Sta. Bul. No. 347, p. 91.

12. Forbes, E. B., and associates (1916-1922), Ohio Agricultural Experiment Station, Bulletins 295, 308, 330, and 363.

13. Hart, E. B., Steenbock, H., and Hoppert, C. A., The Journal of Biological Chemistry, Vol. 53, 21, (1922).

14. Hart, E. B., Steenbock, H., and Hoppert, C. A., The Journal of Biological Chemistry, Vol. 48, 33, (1921).

15. Hart, E. B., Steenbock, H., Hoppert, C. A., and Bethke, R. M., The Journal of Biological Chemistry, Vol. 54, 75, (1922).

16. Meigs, E. B., Blatherwich, N. R., and Cary C. A., The Journal of Biological Chemistry Vol. 40, 468 (1919).

17. Meigs, E. B., Journal of Dairy Science, Vol. VI, No. 1, 1923.

18. Forbes, E. B. and associates, Ohio Agr. Exp. Sta. Bul. 363, p. 36.

TABLE I.—Breed, Dates of Birth, Dates of Freshening, and Average Live Weight of Animals During the Balance Experiments, and Monthly Weights Preceding and Following

	Cow 111 Holstein-Friesian		Cow 146 Holstein-Friesian grade		Cow 154 Holstein-Friesian		Cow 192 Holstein-Friesian grade	
Born	January 31, 1913		April 10, 1915		July 17, 1915		August 28, 1921	
Freshened	1921 December 30, 1920	1922 January 20, 1922	1921 February 12, 1921	1922 June 8, 1922	1921 December 25, 1920	1922 January 21, 1922	1921 March 18, 1921	1922 March 31, 1922
	Live weights, pounds							
January	1,457	1,685	1,333	1,074	1,262	1,575	1,111	1,146
February	1,330	1,415	1,396	1,120	1,160	1,281	1,188	1,239
March	1,306	1,371	1,103	1,195	1,141	1,223	1,292	1,324
April	1,334	1,408	1,013	1,308	1,150	1,185	1,114	1,380*
May	1,292	1,311	948	1,376	1,122	1,120	1,005	1,096
June	1,272	1,332	975	1,437	1,116	1,133	985	1,105
July	1,295	1,355	985	1,149	1,138	1,144	1,003	1,110
1st period	1,273	1,330	955	1,083	1,102	1,135	981	1,071
2d period	1,280	1,335	965	1,085	1,107	1,139	974	1,080
3d period	1,297	1,338	974	1,084	1,126	1,145	984	....
4th period	1,298	....	969	....	1,134	....	988	....
5th period	1,297	....	974	....	1,141	....	1,001	....
6th period	1,300	....	974	....	1,142	....	1,000	....
August	1,302	....	977	....	1,146	....	1,002	....
September	1,340	1,354	973	1,076	1,205	1,181	1,018	1,102
October	1,388	1,377	991	1,087	1,276	1,215	1,017	1,137
November	1,519	1,406	999	1,106	1,401	1,281	1,053	1,163
December	1,620	....	1,036	....	1,486	....	1,105	....

*Weight 1,380, March 28, 1922; 1,180, April 4, 1922.

TABLE II.—Showing Kind and Amount of Feed Supplied Daily, Pounds

	Cow 111		Cow 146		Cow 154		Cow 192	
	1921	1922	1921	1922	1921	1922	1921	1922
Clover hay	5.0	12.0	12.0	5.5	5.0	4.5	12.0	11.0
Timothy hay	5.0	2.4	2.4	5.5	5.0	6.75	2.4	....
Beet pulp	8.25	6.0	1.8	8.25	8.25	10.95	1.8	2.75
Corn	6.0	3.6	2.4	8.25	6.0	6.75	2.4	....
Bran	3.0	3.6	2.4	2.75	3.0	2.25	2.4	3.30
Cottonseed meal	.3	3.0	3.0	.55	.3	....	3.0	3.30
Linseed oilmeal O. P.	.3	3.0	3.0	.55	.3	.....	3.0	3.30
Special gluten meal	......	1.2	......	......	......	....	....	5.22
Nutritive ratio	1:9	1:4	1:4	1:9	1:9	1:11	1:4	1:2

TABLE III.—Analysis of Feeds Used, Percent

	Dry matter		Protein		Ether extract		Crude fiber		Ash		Nitrogen-free extract	
	1921	1922	1921	1922	1921	1922	1921	1922	1921	1922	1921	1922
Clover hay	90.60	85.82	11.83	12.15	2.20	2.39	32.78	29.24	7.33	6.12	36.59	35.92
Timothy hay	91.68	92.50	4.04	6.47	1.99	1.99	32.48	33.62	4.75	5.03	48.55	45.39
Beet Pulp	90.92	90.70	8.47	8.56	.91	.57	20.67	18.66	3.14	2.96	57.73	59.95
Corn	88.44	87.70	8.66	9.06	3.86	4.22	1.86	2.05	1.38	1.25	72.68	71.12
Bran	89.26	91.00	16.09	14.06	3.97	4.80	9.43	10.14	7.28	7.04	52.49	54.96
Cottonseed meal	91.87	91.25	44.13	42.00	8.65	7.48	7.07	7.87	6.52	6.94	25.50	26.96
Linseed oilmeal	89.57	91.00	29.25	34.31	6.69	7.13	9.58	8.64	6.35	5.92	37.70	35.00
Special gluten feed	....	92.20	....	66.00	.....	4.25	.....	.88	......	1.23	....	19.84

TABLE IV.—Showing Ingredients of Daily Ration, Kilograms

Cow	Dry matter		Crude protein (Nitrogen x 6.25)		Ether extract		Crude fiber		Ash		Nitrogen-free extract	
	1921	1922	1921	1922	1921	1922	1921	1922	1921	1922	1921	1922
111	11.404	14.047	1.230	2.740	0.309	0.537	2.455	2.894	0.545	0.786	6.869	7.091
146	11.073	12.714	2.024	1.490	.443	.385	2.655	2.511	.746	.556	5.213	7.774
154	11.404	12.686	1.230	1.290	.309	.316	1.455	2.716	.545	.535	6.869	7.829
192	11.073	11.687	2.024	3.628	.443	.517	2.655	2 111	.746	.669	5.213	4.760

TABLE V.—Average Coefficients of Digestibility Used in These Calculations (Henry & Morrison, 16th ed.)

Feeding stuff	Dry matter	Crude protein	Ether extract	Crude fiber	Ash	Nitrogen-free extract
Clover hay................	59	59	57	54	....	66
Timothy hay.............	55	48	50	50	....	62
Beet pulp (dry)..........	75	52	90*	83	....	83
Corn.....................	90	74	93	57	....	94
Wheat bran..............	65	78	98	31	....	72
Cottonseed meal..........	77	84	95	37	....	75
Linseed oilmeal....... ..	79	89	89	57	....	78
Special gluten meal†	88	85	93	55	....	90

*Assumed. †Same figures used as given in tables for ordinary gluten meal.

TABLE VI.—Average Daily Production of Fresh and of Air-dry Feces, Kilograms

Cow	Average daily feces		Air-dry matter in feces, percent		Air-dry feces	
	1921	1922	1921	1922	1921	1922
121...............	25.88	31.11	15.6	16.2	4.037	5.040
146................	24.26	28.22	18.3	15.7	4.440	4.431
154.	28.05	29.65	15.6	15.5	4.376	4.596
192................	27.47	23.44	16.2	18.6	4.450	4.360

TABLE VII.—Average Analysis of Air-dry Feces, Percent

Cow	Dry matter		Crude protein		Ether extract		Crude fiber		Ash		Nitrogen-free extract	
	1921	1922	1921	1922	1921	1922	1921	1922	1921	1922	1921	1922
111	90.81	90.34	13.31	15.75	4.16	3.48	29.65	26.63	9.07	9.85	34.63	34.63
146	90.88	92.47	13.53	13.63	3.48	2.91	32.78	26.04	9.47	7.26	31.59	42.64
154	91.25	92.17	12.79	12.38	3.61	3.48	28.67	27.11	8.07	7.08	37.95	42.11
192	91.38	92.61	13.51	23.06	3.32	3.12	35.03	24.75	9.72	10.44	29.87	31.25

TABLE VIII.—Ingredients of Average Daily Feces, Kilograms

Cow	Dry matter		Crude protein		Ether extract		Crude fiber		Ash		Nitrogen-free extract	
	1921	1922	1921	1922	1921	1922	1921	1922	1921	1922	1921	1921
111	3.666	4.551	0.537	0.793	0.168	0.175	1.197	1.342	0.366	0.497	1.398	1.745
146	4.035	4.097	.601	.604	.155	.129	1.455	1.154	.420	.322	1.403	1.889
154	3.993	4.239	.560	.569	.158	.160	1.255	1.247	.353	.327	1.659	1.937
192	4.066	4.026	.601	1.001	.148	.131	1.559	1.077	.433	.454	1.329	1.363

TABLE IX.—Ingredients of Ration Minus Those (of Feces) Ingredients Apparently Digested, Kilograms

Cow	Dry matter		Crude protein		Ether extract		Crude fiber		Ash		Nitrogen-free extract	
	1921	1922	1921	1922	1921	1922	1921	1922	1921	1922	1921	1922
111	7.738	9.496	0.693	1.947	0.141	0.362	1.258	1.552	0.179	0.289	5.471	5.346
146	7.038	8.617	1.423	.886	.288	.256	1.200	1.357	.326	.234	3.810	5.885
154	7.411	8.447	.670	.721	.151	.156	1.200	1.469	.192	.208	5.210	5.892
192	7.007	7.661	1.423	2.627	.295	.386	1.096	1.034	.313	.215	3.884	3.397

TABLE X.—Calculated and Observed Digestibilities

Cow	Nutritive ratio	Dry matter		Crude protein		Ether extract		Crude fiber		Nitrogen-free extract	
		Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.
111	1:9	70.1	67.9	65.5	56.3	73.9	45.6	58.9	51.2	79.3	79.6
154	1:9	70.1	65.0	65.5	54.5	73.9	48.8	58.9	48.9	79.3	75.8
146	1:9	71.8	67.8	65.4	59.5	77.9	66.4	59.6	54.0	80.7	75.7
154	1:11	70.8	66.6	60.3	55.9	74.9	49.3	61.6	54.1	79.9	75.3
Average		70.7	66.8	64.2	56.6	75.2	52.5	59.8	52.1	79.8	76.6
Difference....		—3.9		—7.6		—22.7		—7.7		—3.2	
146	1:4	65.8	63.6	75.1	70.3	74.6	65.0	50.4	45.2	73.1	73.1
192	1:4	65.8	63.3	75.1	70.3	74.6	66.6	50.4	41.3	73.1	74.5
111	1:4	69.7	67.6	72.4	71.1	78.4	67.4	56.8	53.6	76.6	75.4
192	1:2	71.1	65.6	79.7	72.4	80.8	74.7	54.8	49.0	74.2	71.4
Average,......		68.1	65.0	75.6	71.0	77.1	68.4	53.1	47.3	74.3	73.6
Difference ...		—3.1		—4.6		—8.7		—5.8		—0.7	

TABLE XI.—Average Daily Production, Milk, and Milk Constituents

Cow	Year	Milk production kgs.	Nitrogen percent	Fat percent	Solids percent	Nitrogen in milk grams	Fat in milk kgs.	Water returned with milk kgs.	Solids in milk kgs.
111	1921	13.763	0.408	2.72	11.76	56.2	0.374	12.176	1.587
111	1922	17.314	.454	2.97	12.03	78.6	.514	15.291	2.093
146	1921	14.401	.404	3.42	13.31	57.0	.482	12.224	1.877
146	1922	23.678	.401	3.06	11.95	95.0	.725	20.849	2.829
154	1921	13.874	.435	2.95	11.69	60.3	.409	12.253	1.622
154	1922	14.925	.433	2.93	12.04	64.7	.437	13.128	1.797
192	1921	14.693	.428	3.42	11.90	62.9	.503	12.944	1.749
192	1922	14.636	.456	3.70	12.60	66.7	.542	12.792	1.448

TABLE XII.—Average Daily Elimination of Urine and Its Constituents

Cow	Year	Urine vol. c. c.	Av. spec. gravity 25° C.	Weight kgs.	Solids gr. in 1 liter	Total weight solids, kg.	Weight water, kgs.	Nitrogen gr. per c. c.	Weight, gr. daily nitrogen
111	1921	13,394	1.015	13.600	39.8	0.533	13.067	0.00416	55.79
111	1922	21,464	1.019	21.868	49.0	1.053	20.815	.00998	214.30
146	1921	25,391	1.014	25.756	36.4	.925	24.831	.00635	160.11
146	1922	11,778	1.0135	11.937	35.0	.412	11.525	.0037	43.52
154	1921	12,505	1.023	12.796	59.8	.748	12.048	.00312	39.00
154	1922	16,004	1.012	16.194	35.0	.494	15.700	.00219	35.00
192	1921	15,368	1.023	15.726	59.8	.915	14.811	.01114	171.25
192	1922	34,630	1.011	34.995	27.2	.942	34.053	.00966	334.10

TABLE XIII.—Average Daily Nitrogen Supplied in Water, Average Daily Nitrogen Lost in Hair, etc.

Cow	Year	Water supplied kgs.	Grams nitrogen per liter water	Nitrogen supplied in water gram	Weight brushings etc. grams	Nitrogen percent	Nitrogen recovered in brushings grams
111	1921	60.27	0.0020	0.12	36.3	6.0	2.21
111	1922	76.26	.0016	.12	15.4	9.4	1.45
146	1921	69.28	.0020	.14	21.0	5.9	1.20
146	1922	68.90	.0016	.11	10.8	9.2	1.00
154	1921	61.23	.0020	.12	33.4	5.9	1.98
154	1922	65.08	.0016	.10	13.0	10.4	1.35
192	1921	62.17	.0020	.12	21.6	6.4	1.37
192	1922	77.15	.0016	.12	6.0	9.1	.55

TABLE XIV.—Average Daily Nitrogen Balance, Grams

Cow	Year	Nitrogen intake in			Nitrogen outgo in					Balance	Balance excluding hair, etc.
		Food	Water	Total	Milk	Urine	Feces	Hair, etc.	Total		
111	1921	196.80	0.12	196.92	56.16	55.80	85.78	2.21	199.95	−3.03	−0.82
111	1922	438.40	.12	438.52	78.62	214.30	126.97	1.45	421.34	+17.18	+18.63
146	1921	323.89	.14	324.03	57.02	164.00	95.99	1.20	318.21	+5.82	+7.02
146	1922	238.32	.11	238.43	95.02	43.51	96.56	1.00	236.09	+2.34	+3.34
154	1921	196.80	.12	196.92	60.28	38.99	89.45	1.98	190.70	+6.22	+8.20
154	1922	206.5	.10	206.60	64.68	35.02	91.04	1.35	192.09	+14.51	+15.90
192	1921	323.89	.12	324.01	62.92	171.25	95.06	1.37	330.60	−6.59	−5.22
192	1922	580.56	.12	580.68	66.74	334.11	160.20	.55	561 60	+19.08	+19.63

TABLE XV.—Comparison of Daily Food Requirement and Food Supply, Using Haecker's* Standard and Both Average and Observed Coefficients of Digestibility, Pounds

Cow	Year	Required		Supplied				Excess or deficit (—)			
		Digestible		Average coef.		Observed digestibility		Average digestibility		Observed digestibility	
		Protein	Carb. eq.	Protein	Carb. eq.	Protein	Carb. eq.	Protein	Carb. eq.	Protein	Carb. eq.
111	1921	2.228	16.103	1.786	16.425	1.530	15.57	—0.442	+0.322	—0.689	—0.533
111	1922	2.718	18.628	4.376	17.434	4.265	17.037	+1.658	—1.194	+1.547	—1.591
146	1921	2.170	14.900	3.370	13.053	3.140	12.440	+1.200	—1.847	+.970	—2.460
146	1922	3.222	20.374	2.149	18.557	1.954	17.237	—1.073	—1.817	—1.268	—3.137
154	1921	2.238	15.407	1.786	16.425	1.480	15.130	—.452	+1.018	—.758	—.277
154	1922	2.330	15.931	1.717	18.664	1.590	16.996	—.613	+2.733	—.740	+1.065
192	1921	2.267	15.517	3.370	13.053	3.160	12.420	+1.103	—2.464	+.893	—3.097
192	1922	2.404	16.619	6.374	12.408	5.784	11.682	+3.970	—4.211	+3.380	—4.937

*In our application of Haecker's Standard the requirement for digestible fat is included under the head of carbohydrate equivalent, the conventional factor 2.25 being used for its conversion.

TABLE XVI.—Food Requirement and Supply, Armsby's Standard, Using Armsby's Average Values for Composition of Feeds Supplied

Cow	Year	Required		Supplied		Excess or deficit	
		True prot. lb.	Net energy therms	True prot. lb.	Net energy therms	True prot. lb.	Net energy therms
111	1921	1.865	13.720	1.382	17.820	—0.483	+4.100
111	1922	2.242	15.230	3.757	21.830	+1.515	+6.600
146	1921	1.858	13.077	3.053	15.440	+1.195	+2.363
146	1922	2.786	17.496	1.674	21.387	—1.112	+3.891
154	1921	1.869	12.909	1.382	17.820	—.487	+4.911
154	1922	1.951	13.368	1.182	20.449	—.769	+7.081
192	1921	1.927	13.564	3.053	15.440	+1.126	+1.876
192	1922	2.032	14.466	5.573	10.389	+3.541	+3.923

TABLE XVII.—A Study of Water Consumption and Elimination, Weight in Pounds

Cow	Year	Daily water consumed	Dry matter consumed	Protein consumed	Water lost in			Water consumed per 1000 lbs. live weight	Nutritive ratio
					Milk	Feces	Urine		
111	1921	132.9	25.15	2.71	26.83	49.02	28.75	102.6	1:9
111	1922	168.1	30.97	6.04	33.58	58.56	45.79	125.9	1:4
146	1921	142.8	24.42	4.47	26.95	44.59	54.62	147.2	1:4
146	1922	151.5	28.03	3.29	45.81	53.18	25.34	139.8	1:9
154	1921	135.0	25.15	2.71	27.45	53.07	26.51	119.5	1:9
154	1922	143.5	27.97	2.85	28.97	56.07	34.54	133.5	1:11
192	1921	137.1	24.42	4.47	28.53	51.64	32.58	138.3	1:4
192	1922	170.1	25.77	8.01	28.20	50.63	74.90	158.2	1:2
Av. wide ration		140.7	26.58	2.89	32.26	52.83	28.78	123.9	....
Av. narrow ration		154.5	26.40	5.75	29.31	51.35	51.97	142.4	....

TABLE XVIII.—Study of Fat Supply and Fat Production, Daily Basis

Cow	Year	Milk production kgs.	Fat percent	Fat production kg.	Total fat in food kg.	Fat in feces kg.	Digested fat kg.	Excess milk fat over digested fat kg.	Excess milk fat over digested fat lb.	Ration
111	1921	13.76	2.72	0.3744	0.3090	0.1677	0.1414	0.2329	0.5135	W
111	1922	17.31	2.97	.5135	.5365	.1750	.3614	.1521	.3354	N
146	1921	13.87	3.42	.4744	.4427	.1545	.2882	.1862	.4106	W
146	1922	23.68	3.07	.7269	.3848	.1290	.2558	.4711	1.039	W
154	1921	14.10	2.95	.4150	.3090	.1576	.1514	.2636	.5812	W
154	1922	14.93	2.93	.4379	.3157	.1596	.1561	.2818	.6214	V W
192	1921	14.69	3.42	.5024	.4427	.1469	.2958	.2066	.4556	N
192	1922	14.64	3.71	.5435	.5173	.1310	.3859	.1576	.3475	V N
Average wide ration				.4883	.4296	.....	.1762	.3121	.6880	....
Average narrow ration				.5084	.4848	.....	.3328	.1756	.3873	....

TABLE XIX.—A Study of Protein Supply and Protein Requirement Weights, Grams

Cow	Year	Daily N balance	Supplied in protein: Total protein	Supplied in protein: Digested protein	Protein in milk	Difference, available for all other purposes	Required for maintenance: Crude protein Hæcker's std.	Required for maintenance: True protein Armsby's std.
111	1921	—3.03	1,230	694	359	335	411	271
111	1922	+17.18	2,740	1,937	501	1,436	423	....
146	1921	+5.82	2,024	1,424	354	1,060	308	....
146	1922	+2.34	1,490	885	606	279	358	239
154	1921	+6.22	1,230	671	385	286	359	245
154	1922	+14.51	1,290	721	413	308	344	248
192	1921	—6.59	2,024	1,433	401	1,032	314	....
192	1922	+19.03	3,628	2,622	426	2,196	341	....

TABLE XX.—Mineral Composition of Feeds (as Weighed for Rations), Percent

Feed		Phosphorus	Sulphur	Calcium	Magnesium	Nitrogen
Clover hay	1921	0.1825	0.1762	0.9736	0.3003	1.893
	1922	.1738	.1783	1.1136	.3287	1.944
Timothy hay	1921	.0942	.1196	.2547	.1166	.646
	1922	.1813	.1536	.2596	.1067	1.035
Beet pulp	1921	.0600	.2783	.7070	.3948	1.355
	1922	.0702	.2350	.6734	.3069	1.370
Corn	1921	.2174	.1199	.0144	.1586	1.385
	1922	.2137	.1176	.0109	.1092	1.450
Wheat bran	1921	1.3712	.2157	.0948	.6674	2.575
	1922	1.5161	.2188	.1067	.6010	2.250
Cottonseed meal	1921	1.2241	.4847	.2110	.6814	7.060
	1922	1.3851	.4672	.1837	.7076	6.720
Oilmeal	1921	.8863	.3130	.3292	.5696	4.680
	1922	.6995	.3659	.3322	.5416	5.490
Gluten meal 1922		.5453	.9430	.0191	.0400	10.560
Water	1921	....	.0001	.0066	.0016	.0002
	1922	....	.00005	.0048	.0017	.00016

TABLE XXI.—Amounts and Percentage Composition of Milk Produced During the Experiments

Cow	Test	Day of lactation	Amount grams	Amount pounds	Fat percent	Phosphorus percent	Sulphur percent	Calcium percent	Magnesium percent	Nitrogen percent
111	1921	195	13,762.8	30.34	2.72	0.0861	0.0232	0.0966	0.0118	0.408
	1922	175	17,313.7	38.18	2.97	.0775	.0259	.1047	.0114	.454
154	1921	200	14,100.7	31.09	2.95	.0827	.0255	.0934	.0115	.435
	1922	181	14,925.3	32.91	2.93	.1814	.0272	.1009	.0112	.433
146	1921	153	13,873.6	30.59	3.42	.0824	.0244	.1037	.0098	.404
	1922	44	23,678.3	52.20	3.06	.0795	.0248	.1152	.0118	.401
192	1921	117	14,692.9	32.39	3.42	.0858	.0240	.0895	.0109	.428
	1922	112	14,635.6	32.27	3.70	.0770	.0262	.1014	.0127	.456

TABLE XXII.—Average Daily Balances of Minerals and Nitrogen, Grams. Cow 111—1921, N. R. 1:9

	Amount	Phosphorus	Sulphur	Calcium	Magnesium	Nitrogen
Intake						
Clover hay	2,268	4.14	4.00	22.08	6.81	42.93
Timothy hay	2,268	2.14	2.71	5.78	2.65	14.65
Beet pulp	3,742	2.25	10.41	26.46	14.77	50.70
Corn	2,722	5.92	3.26	.39	4.32	37.70
Wheat bran	1,360	18.65	2.91	1.29	9.08	35.02
Cottonseed meal	136	1.67	.66	.29	.93	9.60
Oilmeal	136	1.21	.43	.45	.78	6.37
Total	12,632	35.98	24.38	56.74	39.34	196.97
Water	60,262	....	.06	3.98	.96	.12
Total intake	....	35.98	24.44	60.72	40.30	197.09
Outgo						
Milk	13,763	11.86	3.20	13.30	1.63	56.16
Urine	13,394 c.c.	.25	9.86	3.02	9.91	55.79
Feces	4,022	27.40	12.07	45.15	28.49	85.77
Total outgo	..... .	39.51	25.13	61.47	40.03	197.72
Balance	.... ..	—3.53	—.69	—.75	+.27	—.63

TABLE XXIII.—Average Daily Balances of Minerals and Nitrogen, Grams. Cow 154—1921, N. R. 1:9

	Amount	Phosphorus	Sulphur	Calcium	Magnesium	Nitrogen
		Intake				
Clover hay	2,268	4.14	4.00	22.08	6.81	42.93
Timothy hay	2,268	2.14	2.71	5.78	2.65	14.65
Beet pulp	3,742	2.25	10.41	26.46	14.77	50.70
Corn	2,722	5.92	3.26	.39	4.32	37.70
Wheat bran	1,360	18.65	2.91	1.29	9.08	35.02
Cottonseed meal	136	1.67	.66	.29	.93	9.60
Oilmeal	136	1.21	.43	.45	.78	6.37
Total	12,631	35.98	24.38	56.74	39.34	196.97
Water	61,232	....	.06	4.04	.98	.12
Total intake	....	35.98	24.44	60.78	40.32	197.09
		Outgo				
Milk	14,401	11.68	3.59	13.17	1.63	60.28
Urine	12,505c.c.	.16	8.37	1.62	7.68	38.98
Feces	4,368	24.94	12.65	46.17	31.90	89.45
Total outgo	....	36.78	24.61	60.96	41.21	188.71
Balance	....	—.80	—.17	—.18	—.89	+8.38

TABLE XXIV.—Average Daily Balances of Minerals and Nitrogen, Grams. Cow 146—1921, N. R. 1:4

	Amount	Phosphorus	Sulphur	Calcium	Magnesium	Nitrogen
		Intake				
Clover hay	5,444	9.94	9.59	53.00	16.35	103.06
Timothy hay	1,088	1.03	1.30	2.77	1.27	7.03
Beet pulp	816	.49	2.27	5.77	3.22	11.06
Corn	1,088	2.37	1.31	.16	1.73	15.07
Wheat bran	1,088	14.92	2.33	1.03	7.26	28.02
Cottonseed meal	1,360	16.65	6.59	2.87	9.27	96.02
Oilmeal	1,360	12.05	4.26	4,48	7.75	63.65
Total	12,244	57.45	27.65	70.08	46.85	423.91
Water	69,283	....	.07	4.57	1.10	.14
Total intake	....	57.45	27.72	74.65	47.95	324.05
		Outgo				
Milk	13,874	11.43	3.38	14.38	1.35	57.02
Urine	25,392 c.c.	.24	12.12	1.52	7.53	163.94
Feces	4,439	50.34	14.12	54.58	39.07	95.99
Total outgo	....	62.01	29.62	70.48	47.95	316.95
Balance	....	—4.56	—1.90	+4.17	00	+7.10

TABLE XXV.—Average Daily Balances of Minerals and Nitrogen, Grams. Cow 192—1921, N. R. 1:4

	Amount	Phosphorus	Sulphur	Calcium	Magnesium	Nitrogen
			Intake			
Clover hay	5,444	9.94	9.59	53.00	16.35	103.06
Timothy hay	1,088	1.03	1.30	2.77	1.27	7.03
Beet pulp	816	.49	2.27	5.77	3.22	11.06
Corn	1,088	2.37	1.31	.16	1.73	15.07
Wheat bran	1,088	14.92	2.33	1.03	7.26	28.02
Cottonseed meal	1,360	16.65	6.59	2.87	9.27	96.02
Oilmeal	1,360	12.02	4.26	4.48	7.75	63.65
Total	12,244	57.45	27.65	70.08	46.85	323.91
Water	69,283	....	.06	4.10	1.00	.13
Total intake	....	57.45	27.71	74.18	47.85	324.04
			Outgo			
Milk	14,693	12.61	3.68	13.15	1.59	62.92
Urine	15,368c. c.	.24	12.27	2.39	8.02	171.23
Feces	4,438	49.37	13.55	54.29	34.14	95.62
Total outgo	....	62.22	29.50	69.83	43.75	329.77
Balance	....	—4.77	—1.79	+4.35	+4.10	—5.73

TABLE XXVI.—Average Daily Balances of Minerals and Nitrogen, Grams. Cow 111—1922, N. R. 1:4

	Amount	Phosphorus	Sulphur	Calcium	Magnesium	Nitrogen
			Intake			
Clover hay	5,443.2	9.46	9.71	60.62	17.89	105.82
Timothy hay	1,088.6	1.97	1.67	2.83	1.16	11.27
Beet pulp	2,721.6	1.91	6.40	18.33	8.35	37.29
Corn	1,633.0	3.49	1.92	.18	1.78	23.68
Wheat bran	1,633.0	24.76	3.57	1.74	9.81	36.74
Cottonseed meal	1,360.8	18.85	6.36	2.50	9.63	91.45
Oilmeal	1,360.8	9.52	4.98	4.52	7.37	74.71
Gluten meal	544.4	2.97	5.13	.10	.22	57.49
Total	15,785.4	72.93	39.74	90.82	56.21	438.45
Water	76,262.5	....	.04	3.66	1.30	.12
Total intake	....	72.93	39.78	94.48	57.51	438.57
			Outgo			
Milk	17,314	13.41	4.48	18.13	1.97	78.62
Urine	21,464 c.c.	.14	16.24	3.66	10.64	214.29
Feces	5,040	54.84	17.41	63.96	41.33	126.97
Total outgo	....	68 39	38.13	85.75	53.94	419.88
Balance	....	+4.54	+1.65	+8.73	+3.57	+18.69

TABLE XXVII.—Average Daily Balances of Minerals and Nitrogen, Grams. Cow 154—1922, N. R. 1:11

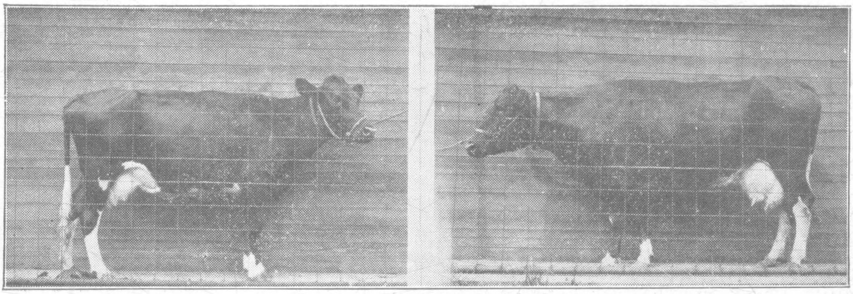
	Amount	Phosphorus	Sulphur	Calcium	Magnesium	Nitrogen
Intake						
Clover hay	2,041.2	3.55	3.64	22.73	6.71	39.68
Timothy hay	3,057.2	5.54	4.70	7.94	3.26	31.64
Beet pulp	4,962.4	3.48	11.66	33.42	15.23	67.99
Corn	3,057.2	6.53	3.60	.33	3.34	44.33
Wheat bran	1,016.0	15.40	2.22	1.08	6.11	22.86
Cottonseed meal	....	....	....	....	....	....
Oilmeal	....	....	....	....	....	....
Gluten meal	....	....	....	....	....	....
Total	14,134	34.50	25.82	65.50	34.65	206.50
Water	65,082	....	.03	3.12	1.11	.10
Total intake	....	34.50	25.85	68.62	35.76	206.60
Outgo						
Milk	14,925	12.15	4.05	15.06	1.67	64.68
Urine	16,004 c. c.	.14	6.92	2.39	7.76	35.02
Feces	4,598	21.55	12.91	51.24	27.03	91.05
Total outgo	....	33.84	23.88	68.69	36.46	190.75
Balance	....	+.66	+1.97	—.07	—.70	+15.85

TABLE XXVIII.—Average Daily Balances of Minerals and Nitrogen, Grams. Cow 146—1922, N. R. 1:9

	Amount	Phosphorus	Sulphur	Calcium	Magnesium	Nitrogen
Intake						
Clover hay	2,494.8	4.34	4.45	27.78	8.20	48.50
Timothy hay	2,494.8	4.52	3.83	6.48	2.66	25.82
Beet pulp	3,742.2	2.63	8.79	25.20	11.49	51.27
Corn	3,742.2	8.00	4.40	.41	4.09	54.26
Wheat bran	1,247.4	18.91	2.73	1.33	7.50	28.07
Cottonseed meal	249.4	3.45	1.17	.46	1.77	16.76
Oilmeal	249.4	1.75	.91	.83	1.35	13.69
Gluten meal	....	....	....	....	....	....
Total	14,220.2	43.60	26.28	62.49	37.06	238.37
Water	68,900	....	.03	3.31	1.17	.11
Total intake	....	43.60	26.31	65.80	38.23	238.48
Outgo						
Milk	23,678	18.83	5.89	27.28	2.89	95.03
Urine	11,778 c.c.	.14	6.44	.65	7.00	43.52
Feces	4,430	25.15	12.78	41.46	26.06	96.56
Total outgo	....	44.12	25.11	69.39	35.95	235.11
Balance	....	—.52	+1.20	—3.59	+2.28	+3.37

TABLE XXIX.—Average Daily Balances of Minerals and Nitrogen, Grams. Cow 192—1922, N. R. 1:2

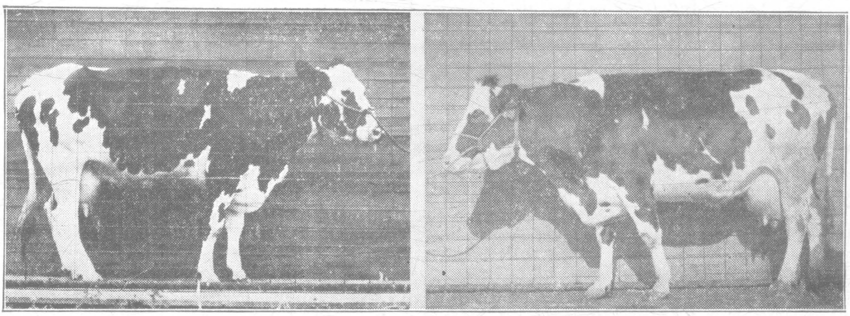
	Amount	Phosphorus	Sulphur	Calcium	Magnesium	Nitrogen
Intake						
Clover hay	4,989.6	8.67	8.90	55.56	16.40	97.00
Timothy hay	....	....	....	....	....	....
Beet pulp	1,247.4	.88	2.93	8.40	3.83	17.09
Corn	....	....	....	....	....	....
Wheat bran	1,496.8	22.69	3.28	1.60	9.00	33.68
Cottonseed meal	1,496.8	20.73	6.99	2.75	10.59	100.59
Oilmeal	1,496.8	10.47	5.48	4.97	8.11	82.17
Gluten meal	2,367.8	12.91	22.33	.45	.95	250.04
Total	13,095.2	76.35	49.91	73.73	48.88	580.57
Water	77,156	....	.04	3.70	1.31	.12
Total intake	....	76.35	49.95	77.43	50.19	580.69
Outgo						
Milk	14,636	11.28	3.84	14.84	1.86	66.80
Urine	34,632 c.c.	2.79	24.78	4.93	7.40	334.12
Feces	4,345	56.35	20.09	53.45	41.06	160.20
Total outgo	....	70.42	48.71	73.22	50.32	561.12
Balance	.. ..	+5.93	+1.24	+4.21	—.13	+19.57



COW 192

July 13, 1921, at beginning of balance period, weight 981 pounds

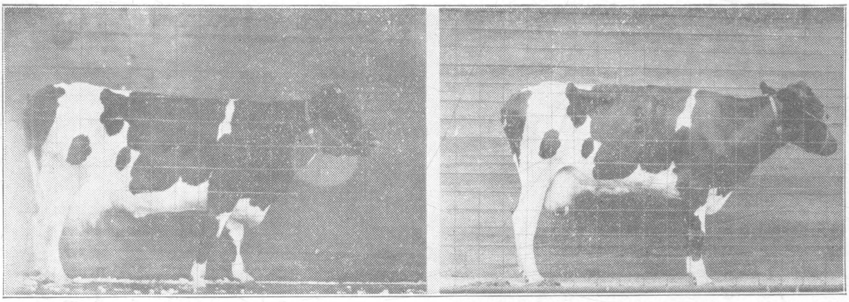
April 24, 1922, 24 days after beginning of a lactation period, weight 1140 pounds



COW 111

July 13, 1921, at beginning of balance period, weight 1273 pounds

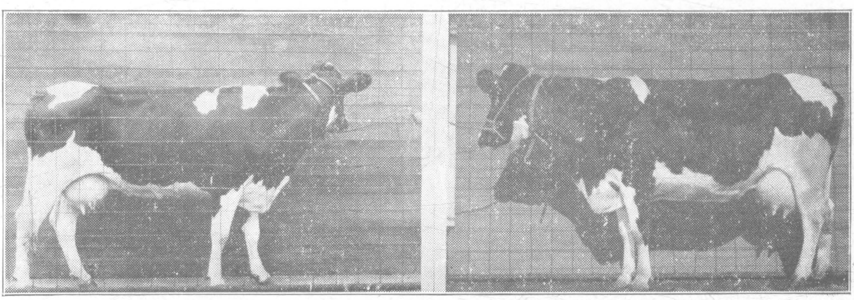
January 28, 1922, one week after freshening, weight 1420 pounds



COW 146

February, 1921, shortly before calving, weight 1395 pounds

July 13, 1921, at beginning of balance period, weight 975 pounds



COW 154

July 13, 1921, at beginning of balance period, weight 1103 pounds

January 4, 1922, 24 days before freshening, weight 1575 pounds