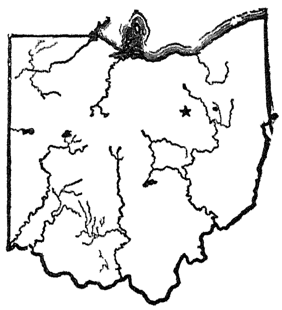
THE MINERAL METABOLISM OF THE MILCH COW

OHIO
Agricultural Experiment Station

WOOSTER, OHIO, U. S. A., SEPTEMBER, 1922

BULLETIN 363



OHIO AGRICULTURAL EXPERIMENT STATION

STATION STAFF

C G. WILLIAMS, *Director*

ADMINISTRATION

THE DIRECTOR, *Chief*
WILLIAM H. KRAMER, *Bursar*
W. K. GREENBANK, *Librarian*

AGRONOMY

C. G. WILLIAMS, *Director, Chief*
F. A. WELTON, M. S., *Associate*
J. B. PARK, Ph. D., *Associate*[1]
L. E. THATCHER, Ph. G., *Assistant*
C. A. PATTON, *Assistant*
C. E. DIKE, B. S., *Field Assistant*
WILLIAM HOLMES, *Farm Manager*

ANIMAL INDUSTRY

G. BOHSTEDT, M. S., *Chief*
D. C. KENNARD, B. S., *Associate*
D. S. BELL, B. S, *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

A. D. SELBY, B. S, *Chief*
TRUE HOUSER, B. S., *Asst.*, (Germantown)
FREDA DETMERS, Ph. D., *Assistant*
ROY C. THOMAS, M. A., *Assistant*
M. J. YOUNG, M. S., *Assistant*

CHEMISTRY

J. W. AMES, M. S., *Chief*
C. J. SCHOLLENBERGER, *Assistant*
MABEL K. CORBOULD, *Assistant*
RAUB H. SIMON, A. M., *Assistant*
V. H. MORRIS, A. B, *Assistant*

CLIMATOLOGY

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

DAIRYING

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

ENTOMOLOGY

H. A. GOSSARD, M. S, *Chief*
HERBERT OSBORN, D. SC., *Associate*[1]
J. S. HOUSER, M. S. A., *Associate*
W. V. BALDUF, M. S., *Assistant*
A. E. MILLER, B. S., *Assistant*

FORESTRY

EDMUND SECREST, B. S., *Chief*
J. J. CRUMLEY, Ph. D., *Assistant*
F. W. DEAN, B. S., *Assistant*
O. A. ALDERMAN, B. S., *Assistant*

HORTICULTURE

J. H. GOURLEY, M. S., *Chief*
W. J. GREEN, *Consulting Horticulturist*
PAUL THAYER, M. S., *Associate*
F. H. BALLOU, *Assistant* (Newark)
C. G. VINSON, M. S., *Assistant*
J. B. KEIL, *Field Assistant*
I. P. LEWIS, B. S., *Field Assistant*
C. W. ELLENWOOD, *Field 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]
A. BONAZZI, B. Agr., *Assistant*
G. W. CONREY, A. M., *Assistant*[1]

FARM MANAGEMENT

C. W. MONTGOMERY, *Chief*
F. D. ECHELBERRY, B. S., *Assistant*
L. B. NETTLETON, *Office Assistant*

DISTRICT EXPERIMENT FARMS

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

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

Southeastern Test-Farm, Carpenter
E. C. SCHWAN, *Foreman*

Northwestern Test-Farm, Findlay
JOHN A. SUTTON, *Manager*

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, Mt. Healthy
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
J. PAUL MARKLEY, *Supt.*, Canfield

Belmont Co. Experiment Farm, St. Clairsville
C. W. MONTGOMERY, *Acting Supt.*, Wooster

STATE FORESTS

Waterloo State Forest, New Marshfield
Dean State Forest, Steece

---

[1]In cooperation with the College of Agriculture, Ohio State University, Columbus.
[2]In cooperation with the U. S. Department of Agriculture.

CONTENTS

BULLETIN

OF THE

Ohio Agricultural Experiment Station

NUMBER 363 SEPTEMBER, 1922

THE MINERAL METABOLISM OF THE MILCH COW

E. B. FORBES, C. H. HUNT, J. A. SCHULZ, A. R. WINTER, AND R. F. REMLER

INTRODUCTION

The rise of mankind out of savagery is but a moment in the history of the species. Civilization is a new garment; but the nutritive requirements of the human animal have evolved as he has evolved, and, in their fundamentals, are as ancient as animal life itself. The aboriginal food habit was nature's own expression of those requirements.

Civilization, however, with its innovations and complications, its surpassing ingenuity and wilful caprice in matters of diet, has profoundly disturbed the natural order. Each year adds its contribution to our knowledge of functional derangement and pathology, as results of departures from those ancient food customs which have come down to us as an inheritance from unnumbered ages.

Primarily because of Man's evolution as a tiller of the soil, and later, as a fabricator of artificial foods, he has been able greatly to increase the proportions of cereals and cereal products in the diet, and also vastly to extend his freedom of choice of foods of all kinds, thus providing almost unlimited means either to perfect or to unbalance his ration.

It is probably true that only through extensive use of cereals as foods can Man exist in present numbers upon the earth, but the newer knowledge of nutrition has shown us that these cereal foods, especially white flour, polished rice, and sugar have rather commonly crowded out of the diet other foods which are richer in calcium, phosphorus, iron, and vitamines; and in some cases animal proteins have been so largely supplanted by certain incomplete vegetable proteins as to cause a lowering of the biological value of the protein of the diet as a whole—notably so in those diets which contribute to the cause of pellagra.

This whole situation requires of us increasing consideration of the dietary, especially of those articles of food which, because of superior balance or quality of nutrients or richness in components often lacking in the diet, are valuable for purposes of nutritional insurance.

Such a food is milk. No one food is complete and perfect, in the sense of sufficing for the nutrition of animals of all ages, but milk is probably as nearly a complete and perfect food as any other. No other can take its natural place as a food for infants, and its high-grade proteins and mineral nutrients, as well as its vitamines, give it great value as a supplementary food for use with artificial and defective diets, not only in the feeding of children, but also of adolescents, and even of adults.

The metabolism of lactation in the cow, therefore, has become a matter of uncommon interest, not only as relating to food production, but also as contributing to our knowledge of general physiology.

The confinement of the scope of this investigation mainly to the mineral elements was due to our imperfect knowledge, and therefore, to our need for light, in this portion of the field, and, further, to the remarkable character of milk as a source of mineral nutriment, especially its phenomenal content of calcium in condition for most ready utilization.

This investigation, involving the determination of 60 balances of intake against outgo with each of the elements sodium, potassium, calcium, magnesium, sulphur, phosphorus, chlorine, and nitrogen, as well as 12 balances of silicon and 6 of arsenic, comprises four studies, three of which have been published in detail, the fourth being the subject of this article.

RESULTS OF EARLIER STUDIES

Our first investigation[1] consisted of 18 balances of income and outgo, during liberal milk production, in the first half of the period of lactation. Normal rations of hay, grain, and silage, fed in quantities sufficient to maintain the live weight and to cause regular nitrogen and sulphur storage, led to invariable losses of calcium

[1]Forbes, E. B., Beegle, F. M., Fritz, C. M., Morgan, L. E., and Rhue, S. N., Ohio Agr. Exp. Station, Bul. 295, 1916.

and magnesium from the body, and also negative balances of phosphorus in 15 instances out of 18. The losses of calcium must certainly have involved drafts upon the mineral substance of the skeleton. The losses of these mineral elements which occurred during the feeding of timothy hay were larger than those occurring during the feeding of clover hay, but the cows were remarkably unresponsive to the large increase in calcium intake brought about by the change of roughage from timothy to clover. A considerable metabolism of silicon was demonstrated, especially as introduced into the ration by the timothy hay. This silicon was present in soluble compounds in amounts sufficient to render acid the normally alkaline urine.

This experiment, then, demonstrated the fact that the elaboration of milk in cows of good productive capacity, while on normal winter rations, involved drafts upon the mineral substance of the skeleton. In subsequent studies we have attempted to illuminate the conditions under which these mineral losses occur, and likewise the terms upon which these overdrafts are made good by storage.

In the second experiment[2] we studied the effects of addition to the ration of large amounts of calcium carbonate, steamed bone flour and sodium chloride, in a series of 12 balances. Calcium was supplied in varying amounts up to double the maximum fed in the previous experiment.

As in the first study all calcium balances were negative. There was loss also of magnesium in all instances but one, but it was found to be possible for the cow to store phosphorus at the same time that she was losing calcium. Excessive supply of calcium and magnesium, then, failed to cause retention or even equilibrium of these elements; and the terms of the general mineral metabolism were not altered in important ways by doubling the intake of common salt.

In the third experiment[3], comprising again 12 complete mineral balances, the calcium content of some of the rations was still further increased, and a study was made of the influence upon the general mineral metabolism of three calcium compounds selected because of their ready solubility—namely, calcium lactate, calcium chloride, and precipitated bone phosphate.

The balances of calcium were, again, all negative; and there was no evidence that the limited utilization of calcium by lactating

[2]Forbes, E. B., Beegle, F. M., Fritz, C. M., Morgan, L. E., and Rhue, S. N., Ohio Agr. Exp. Station, Bul. 308, 1917.

[3]Forbes, E. B., Halverson, J. O., and Morgan, L. E., Ohio Agr. Exp. Station, Bul. 330, 1918.

cows is due to difficult solubility of the calcium compounds of the ration, nor were any of the calcium compounds studied found to possess distinct superiorities over the others in their effects upon the calcium balance.

As in the previous studies the most salient points among the conclusions were the coincident gains in nitrogen (Period II) and losses of mineral nutrients, and especially a strikingly poor utilization of mineral supplements.

In spite of superabundant supplies of calcium, magnesium, and phosphorus in the rations the balances of calcium and phosphorus were in every case negative, and of magnesium eleven balances out of twelve were negative. This limited utilization of mineral nutrients was shown not to be due primarily to their conditions as to solubility.

It was concluded that the mineral metabolism of the well-fed, heavily milking cow is determined first by the inherited impulse to secrete milk, second by the mineral nutrient reserves of the animal body, and only third by the food supply. It appears that the mineral metabolism of lactation is too important a matter to be subjected to the likelihood of extensive influence by conditions of food composition or supply, and is therefore extensively safeguarded by mineral nutrient reserves, and the capacity to draw upon them.

In these three papers are also many observations as to mineral requirements, as to interrelationships and paths of outgo of the mineral elements, as to the significance of positive and negative balances, and as to the practical bearings of the facts observed upon the feeding and management of dairy cattle.

OBJECTS OF THE EXPERIMENTS

Having accomplished a searching inquiry into the mineral metabolism of the milch cow during the period of most active production, and having demonstrated the existence of conditions during this earlier portion of the period of lactation which can not possibly prevail during the entire productive life of the cow, it was our object in this study especially to bring out the facts as to the course of the mineral metabolism through the whole of the annual cycle of lactation and gestation.

To accomplish this purpose the subjects of this experiment were so selected that the series of balance determinations would cover, in a disconnected way, the entire reproductive cycle, in recognition of the facts that the periodic variation in the mineral metabolism is a matter of critical importance, and that, both in relation to physiology and matters of practice, in milk production, the year is the unit.

Secondary objects were to determine the value of the particular mineral supplements used, including arsenic, and to continue our examination into the conditions of the general mineral metabolism of the cow.

METHODS OF EXPERIMENTATION

The method of this study, as of the preceding three, involved the complete chemical accounting for feed, milk, urine, and feces. The details of procedure were as published in Bulletin 295. As in the earlier experiments six Holstein-Friesian cows were used, in three series of balance determinations, the collection periods being either 16 or 20 days in length, except as shorter periods were necessitated by the exigencies of the difficult experimental program. The collection periods were normally separated by 10-day intervals during which the subjects received the same ration that was to be used in the collection period to follow. The length of this intermediate period was extended in cases in which difficulty was experienced in getting the subjects onto a satisfactory basis of feed consumption and of general behavior.

The experimental subjects.—The experimental subjects were all mature cows, in their prime (with one exception, to be noted), and were either high grades or pure-breds of first-class utility type. The cows in full milk varied from good to very good producers, as evidenced by their average daily milk yields of 37.87 to 61.36 pounds. All were in perfect health except No. 7, the history of which, subsequent to the completion of the experiment, indicates that she was not in normal condition during the investigation, but this fact seems to have had no important effects upon the results obtained in this study.

From the second column in Table I, page 46, it will be seen that Cows 1, 2, 5, and 6 were discarded after the close of Period I, and were replaced by Cows 7, 8, 9, and 10. The discarded cows represented stages in the annual cycle which had been covered in earlier experiments, but were included in Period I in order to have the whole year represented in one experimental program. The cows were entirely dry in seven balance determinations, and in four more were giving less than 10 pounds of milk per day. In the remaining seven balance determinations the cows yielded from 37.87 to 61.36 pounds of milk per day.

Length of balance periods.—In eleven cases out of eighteen we were successful in keeping the cows in satisfactory condition for experimentation during the whole of the collection periods of 16 to 20 days as contemplated, but in the remaining seven cases the unusual difficulties of our experimental program required greater or less abbreviation of the collection periods. Results from the shorter periods are certainly of less value than those from the 16 to 20-day periods, but, even so, were mostly longer than the greater part of those reported in the literature.

Position of balance periods in annual cycle.—The fourth and fifth columns of Table II, page 46, indicate the situation of the cows in the year of lactation and gestation. It will be noted that they were selected more especially to cover the first two-thirds of the period of lactation and the last third of the period of gestation, that is, the times of greatest utilization of nutriment for the elaboration of milk, for the growth of the fetus, and for the restoration of losses from the nutritive stores of the body, as caused by the functional activities prevailing.

It will be noted that these balance periods cover the entire reproductive cycle, from the first day of lactation to the day before parturition. The selection of experimental subjects to serve the exacting requirements of this program was attended with difficulty and compromise, since the cows were of necessity purchased especially for this test, and since, to the uncertainties due to the natural variability in the reproductive activity of the cow, there were added further embarrassments resulting from the human element in the problem, especially in connection with unreliable breeding records.

Experimental rations.—The distinguishing features of the treatment given the six cows in each period are set forth in Tables I and II, page 46.

It will be noted that the cows were usually selected in pairs at about the same stage in the period of lactation and gestation, and that one of each pair was given a mineral supplement, while the other, for comparison, received the basal ration alone.

The same mineral supplement was used in all cases, being a half-and-half mixture of precipitated bone phosphate and precipitated calcium carbonate. The former is a by-product of gelatine manufacture, while the latter is a by-product of the manufacture of sodium hydrate, in soap making.

In the choice of this mineral supplement it was our design to supply calcium in readily soluble form; the precipitated bone phosphate, being selected because cheap and readily accessible and also a carrier of a useful acid element. The precipitated carbonate was added to the phosphate in order to supplement the calcium of the former, which, from a nutritional point of view, may be considered as present in deficient amount as compared with phosphorus. The half-and-half proportion was determined arbitrarily. Of this mixture we fed a sufficient amount to supply, in each case, 70 milligrams of calcium per kilogram of live weight per day, based on live weights during preliminary or intermediate periods.

The basal ration in Periods I and II was composed of corn meal 13 parts, and 1 part each of cottonseed meal, linseed oilmeal, and wheat bran, with alfalfa hay virtually ad libitum, and common salt in weights equal to seven-thousandths that of the grain.

It was found, however, that with alfalfa hay as the sole roughage this ration was more laxative than was desired. On this account the linseed oilmeal was eliminated in Period III, and the proportions of cottonseed meal and wheat bran were increased to make the basal ration corn meal 5 parts, cottonseed meal 1 part and wheat bran 2 parts.

These rations were of normal, standard type, but differed from the best in lacking corn silage.

The amounts of feed first offered the cows were determined by computation of their requirements. These amounts were then readjusted to meet the individual peculiarities of the subjects.

Arsenic in the form of Fowler's solution was fed to each of the six subjects, in Period III. The reasons for the inclusion of arsenic in this study were; (1) that arsenic is being used as a component of certain commercial feeds for cows, (2) that there is evidence in the literature in support of the idea that arsenic is effective to stimulate calcium retention, and (3) that the public has an interest in knowing whether arsenic, administered to a cow, is eliminated to an appreciable extent in the milk.

Chemical methods.—The analyses of the products of the investigation were conducted in triplicate, as usual, with as many additional repetitions as were necessary to clear up any apparent possibilities of error. The methods used were as indicated below:

Moisture.—Vacuum method, drying to constant weight over sulphuric acid.

Nitrogen.—The Gunning method, using potassium sulphate, crystalized copper sulphate, and potassium permanganate.

Ether extract.—Continuous extraction with ether in alundum thimbles for 48 hours. For milk the residues from the moisture determination were disintegrated, placed in alundum thimbles, and then extracted.

Ash.—Gentle ignition at dull redness, with leaching and filtration, if necessary, or with mere moistening of the charred mass and continuance of gentle ignition.

Crude fiber.—To a sample of feed or feces (2 to 3 grams) add 200 c.c. of 1.25 percent boiling sulphuric acid; boil for 30 minutes, keeping volume constant by addition of water; then add 200 c.c. of 3.52 percent boiling sodium hydrate, and boil 30 minutes, keeping volume constant. Remove alkaline solution by inverse suction through fine linen wired over a thistle tube or carbon tube, with a filter flask interposed between tube and suction pump. Wash with hot water until this comes through clear. Render the solution containing the fiber acid by adding 2 to 4 c.c. of 1.25 percent hydrochloric acid, and let stand to harden the fiber. Filter through a porcelain Gooch crucible and wash with hot water until free from chlorides, then with alcohol and ether. Dry to constant weight, ignite, and weigh. The difference in weight represents crude fiber.

Nitrogen-free extract.—By difference.

Sodium.—Official Methods I and II[4], combined and modified, weighing the combined sulphates of sodium and potassium, determining the latter in the combined sulphates by the potassium perchlorate method of Scholl[5], and sodium by difference. These modified methods by J. O. Halverson, L. E. Morgan, and J. A. Schulz will be published shortly.

Silica.—Moisten the ash with hydrochloric acid, and dehydrate at 110° C. Moisten with hydrochloric acid and again dehydrate. Take up with dilute hydrochloric acid, and filter and wash. Evaporate the filtrate to dryness and repeat the above procedure. Combine the two residues, place in a platinum dish and ignite to constant weight. Moisten the silica with a few drops of sulphuric acid; add about 10 c.c. of hydrofluoric acid and evaporate on the water bath under a hood. Place the dish over a low flame to evaporate the sulphuric acid, and finally ignite to low redness, cool, and weigh. Deduct this weight thus found from the weight of the dish plus residue as found above. This difference represents silica.

Arsenic.—Sanger-Black-Gutzeit method, modified[6].

---

[4]Official and Tentative Methods of Anal., Assn. Offic., Agr. Chem., (Sept., 1920), 18.
[5]Scholl, Clarence; Journ. Am. Chem. Soc. 36, 2085 (1914).
[6]J. Assoc. of Official Agric. Chemists; Vol. III, No. 4, May 15, 1920.

Sulphur.—Benedict method as modified by Halverson.[7]

Calcium.—McCrudden method, modified[8] to use potassium permanganate titration.

Magnesium.—To filtrates from calcium estimation, in casseroles on a steam bath, add 20 c.c. of concentrated nitric acid, followed later by 15 c.c. of concentrated hydrochloric acid; evaporate to small volume and transfer to 60 c.c. evaporating dishes; evaporate to dryness, ignite, dissolve in 10 percent hydrochloric acid, and filter. Estimate by the usual method, weighing as the pyrophosphate.

Chlorine.—Official Volhard method, modified, ashing in the presence of sodium carbonate[9]. The use of the twentieth-normal silver nitrate was found advantageous.

Phosphorus.—A charge sufficient for sodium, potassium and phosphorus estimations was digested with nitric and sulphuric acids. With feeds and feces add hot water to the Kjeldahl flasks containing the charges, to facilitate disintegration; follow with 20 c. c. of concentrated nitric acid, shake occasionally and allow to stand over night. This prevents foaming. Add 20 c. c. of the following mixture, and digest over a free flame.

Concentrated sulphuric acid 600 c. c.

Concentrated nitric acid 800 c. c.

Red fuming nitric acid 400 c. c.

Digest until clear; cool, dilute, filter into a 250 c. c. volumetric flask, make up to volume, and determine phosphorus on an aliquot by the gravimetric method.

---

[7]J. Am. Chem. Soc. Vol. XLI No. 10, 1919.

[8]J. Ind. and Eng. Chem Vol 12, No. 1, p. 77, 1920.

[9]J. Biol. Chem. Vol. XLI No. 2, 1920.

PLATE I

Metabolism stalls; the three at the right are as used while cows are eating; the three at the left are used while cows are lying down.

PLATE I

PLATE II

Metabolism stalls; the two stalls at the right have the stanchion gates swung forward, to give the cows as much freedom to move as practicable; the middle pair of stalls have the gates in position to prevent throwing feed backward out of the manger; the two stalls at the left have their front doors in position, the others having been removed to show the interior.

PLATE II

PLATE III

Metabolism stalls; cows, attendants, and equipment in position.

PLATE III

Metabolism stalls.—The cows were confined in the same stalls which were used throughout the whole series of investigations, although slight changes of construction were made, from time to time, to increase the cows' comfort; thus, the double hinged gates forming the stanchions, as shown in the illustrations on pages 13 and 15, were simplified by cutting off the rear gates of each pair, and holding the remaining pair of gates in position, over the rear edge of the manger, by means of a ¼ inch by 1¼ inch iron bar attached to each door by a staple and carried forward to another staple at the side of the manger. These gates were swung forward, out of the cows' way, except at feeding time.

Daily routine.—No changes in our daily experimental procedures were made subsequent to the establishment of the methods used in our first study[10], the cows being fed and milked four times daily, at 6-hour intervals, and watered twice daily, after the morning and the evening feeding. In this experiment the cows were weighed daily throughout the whole program. As usual the cows were watered with distilled water only, and the greatest of care was used to guarantee the purity of this water. No water was placed in the storage tank without first testing it for contamination. The cows were washed frequently and curried daily. The mattresses on which they stood, or lay, were made over as often as necessary to keep them in good order. The cows were completely adapted to the routine before the beginning of the experiment, including the lights throughout the night, and there is no ground for assuming that any of the peculiarities of the mineral metabolism were due to disturbance caused by the experimental procedures. A chemist was present at all times during the 24 hours, to guarantee correct weights, measures, and conditions of care; and we say, without qualification, that the subjects were in a perfectly normal state of comfort and composure. Lack of exercise may conceivably have affected the mineral metabolism in specific ways, though we have no evidence or knowledge to warrant an assumption that this was true, or likely to be true.

Behavior of experimental subjects.—In general the feeding and experimental program was found uncommonly difficult to manage, on account of the complications introduced by changes of feed requirements, before and after parturition, and by our inability to forecast the day of parturition with an accuracy sufficient for the purposes of our investigation.

---

[10]Ohio Agr. Exp. Sta., Bul. 295.

In the case of Cow 3, Period II, for instance, it was impossible to start this cow, immediately after parturition, on a ration which would maintain the live weight, and satisfy subsequent increase in appetite, without virtual certainty of causing milk fever. In this situation we maintained the cow, during a 7-day balance determination, on exactly the same amount of feed that she had received in the previous experimental period, just before calving. In this previous period this cow gained in live weight 0.89 kilo per day. In the following period, immediately after calving, on the same feed, this cow lost during seven days an average daily weight of 7.08 kilos. A part of this loss was doubtless inevitable, but was also due in part to underfeeding, in consideration of the added requirement for milk production. We chose to conduct this short balance period on this basis since it was the only way in which we could get a correct idea as to the mineral metabolism immediately after calving. This cow was so exceedingly quiet and regular in her behavior, and was so little disturbed by parturition, that we recognized at once that the conditions were favorable for beginning a new collection period. This, therefore, was done immediately and without change of feed intake, as above stated.

The nature of our program necessitated a number of compromises, especially as to length of collection periods.

The average daily gains or losses in live weight of the experimental subjects are set forth in the right-hand column of Table III, page 47. It is significant that in 12 balances out of the 18 the cows gained in weight, and that among the 7 balances in which the cows gave no milk the subjects gained weight in 6 instances. The dry cows gained, on an average, 0.83 kilo, or 1.83 pounds, per head per day.

Among the milking cows the 4 which were nearly dry all gained in weight, while among the 7 in full milk 5 lost and 2 gained in weight.

The maintenance of conditions essential to metabolism investigation makes it impossible to feed cows quite to full capacity. This is on account of the virtual necessity that there be no refused feed, and the impossibility of increasing the amount of the ration during an experimental period, as the cows manifest a desire for increase. The result, therefore, is that the intake of feed is almost always slightly below the maximum, except in those unusual instances in which we have over-estimated the cow's capacity, in which case she may be fed to her full capacity until it becomes necessary to terminate the balance period because of the subject's failure to consume all of the feed.

The results of metabolism investigations such as this, then, should be considered as characteristic of cows which are on practically "full-feed" but not pushed to the limit as in the most successful feeding under conditions of practice; and the lack of exercise, under the conditions which must prevail, doubtless results in some restriction of feed consumption, especially of roughage. In our judgment, however, the differences in intake between our cows on experiment and similar cows fed under conditions of practice are slight, and certainly not sufficient in amount to involve any conspicuous or important differences in gain or loss of mineral nutrients. A significant light is thrown upon this matter by the gains in live weight and in nitrogen, which will be discussed further in connection with the individual mineral balances. Throughout the experiment, except for the one balance of Cow 3 in Period II, we gave the cows the greatest amount of feed that we possibly could, under the circumstances.

RESULTS OF BALANCE DETERMINATIONS

GENERAL DISCUSSION

The main results of the experiment are set forth in Tables X, XI, and XII, pages 54 to 56, which show (1) the average daily milk yield, in grams, and in pounds, (2) the distinguishing features of the experimental feeding, (3) the status of the subjects as to lactation and gestation, (4) the amounts of each of the mineral elements and of nitrogen in feed, milk, urine, and feces, and (5) the balance of income to outgo for each of these elements, eight in number in Periods I and II, and nine in Period III.

The subjects of this experiment having been selected in pairs representing the same stage in the annual cycle, one receiving a mineral supplement and the other the basal ration alone, in each case, we shall consider them in this light.

Cows 1 and 2, Period I, representing days of lactation 139 to 161, were not bred, and with a milk production of 37.87 to 42.77 pounds, exhibited negative mineral balances, as a rule; and these, together with the status of the sulphur and nitrogen balances, indicated a slightly insufficient food intake.

Cows 3 and 4, both dry, representing days of gestation 240 to 265, received feed enough to provide for retention in 12 out of the 16 individual elemental balances, including calcium, phosphorus, sulphur, chlorine, and nitrogen, for both cows. These positive balances are due to the cows, having a sufficiency of feed, being dry, and being in the later part of the period of gestation.

Cows 5 and 6, in full milk, and not bred, days of lactation 50 to 74, like Cows 1 and 2 were slightly underfed, and, being also rather recently fresh, with the lactating impulse still at its height, and the milk secretion liberal (40.63 to 49.61 pounds), the balances were almost all negative.

After this period Cows 1, 2, 5, and 6 were discarded, Nos. 3 and 4 being continued, and Cows 7, 8, 9, and 10 added.

Cows 3 and 4, in Period II, were normally of about the same weight (Table 3, Period I, page 47). In Period II, Cow No. 3 had just calved, and No. 4 was just about to calve. Their feed intake was the same, except that No. 4 was given a mineral supplement. The balances of these cows afford a striking demonstration of the essential character of metabolism at the beginning and at the end of the annual cycle.

Cow 4, during the last five days of pregnancy was storing each of the mineral nutrients and nitrogen at a rapid rate, as shown by the eight positive balances, while No. 3, immediately after parturition, on the same ration, except for the lack of the calcium supplement, lost largely of each of the elements studied. These losses were due in part to the liberation of a flood of nutrients, stored up during gestation, and in part to the insufficiency of the ration. It is interesting and significant that No. 4, just before calving, was storing calcium more rapidly than any other cow at any other period of the annual cycle. We believe that this result fairly represents a fact, that calcium, the balance of which is always negative during the early part of the period of lactation, is stored in abundance during gestation, especially during its last stages.

Cows 7 and 8, representing days 226 to 263 in the period of gestation, one being dry and the other nearly dry, were nearly ready to calve. The balances of sodium, sulphur, chlorine, phosphorus, and nitrogen were all positive, as also was the calcium balance in the case of the dry cow, which was also nearest to calving.

These balances indicate, as in the cases of Cows 3 and 4 in Period II, a sufficiency of feed, and the later and more rapid storage period in the term of gestation.

Cows 9 and 10 were not quite so far along in gestation, but told the same story, of spent impulse to lactate, and of storage in anticipation of parturition, all balances except magnesium being positive. Under these circumstances it seems impossible that the negative magnesium balances signify insufficiency of this nutrient.

The balance data reveal no extensive or certain effect of the administration of calcium supplements on the retention of this element.

In Period III the general record of Cows 3 and 4 was typical of what we have come to expect of fresh cows. They received sufficient amounts of feed to maintain nitrogen equilibrium, but suffered general loss of mineral nutrients.

Cows 7, 8, 9, and 10, all either dry or nearly dry, and all late in the period of gestation, all stored nitrogen, sodium, and calcium, while positive balances also prevailed with the majority of the other elements, except for potassium and magnesium, with which three and two, respectively, out of the four balances were negative.

Composition of the milk.—That the gross composition of the milk is determined by the age, breed, individuality, and state of health of the cow, and by the time in the period of lactation, and not in any definite way by the composition of the ration, is so thoroughly established and generally understood as to require no discussion. Certain of the variations in composition as related to the time elapsed since calving, however, are worthy of note, (Table V, page 49).

Cow 3, Period II, was on experiment during the first 7 days of lactation. The milk from this period included the colostrum. The analysis shows that this milk, as compared with that from Cows 1 and 2, Period I, which between them covered the 139th to the 161st days of lactation, contained approximately twice the proportion of nitrogen, sodium, and sulphur, and a less pronounced excess of each of the other mineral elements. The laxative character of the colostrum may readily be due to the minerals which it holds in solution.

At the other end of the period of lactation stood Cow 7, Period III. This cow was milked only four times during the 16-day period. The secretion was curdy, and distinctly not normal milk. It was very low in fat, sodium, potassium, and calcium, and high in nitrogen, magnesium, sulphur, and chlorine. This milk also contained six parts per million of arsenic, but this fact is thought not to be important in connection with normal milk secretion since this cow was not "giving milk" in the ordinary sense, and the secretion was not of usuable character. The milk of the fresh cows (Nos. 3 and 4) contained no arsenic.

Cows 7, 9, and 10, Period II, were well along toward the end of the period of lactation. They produced from 4 to 10 pounds of milk per head per day. Their milk was normal and usable, but the analysis shows that it differed from milk produced at the middle of the period of lactation by being high in nitrogen and in all of the minerals except potassium, which was distinctly low. Sodium and chlorine were in much greater excess than the other mineral elements.

Composition of the urine.—Table VIII, page 52, shows that calcium was excreted in the urine in lowest amount by the freshest cows (Cow 3, Period II, and Cows 3 and 4, Period III). The natural inference is that this is due to the extent of the outgo of calcium in the milk.

The daily amount of sulphur in the urine was surprisingly nearly the same, while chlorine varied widely. Chlorine excretion in the urine was low in the milking cows, and high in the dry cows. The chlorine excretion in the urine was lowest in the freshest cows, the urine of Cow 3, Period II, a fresh cow, being almost free from chlorine (1.302 gm. per day). The milk and urine may be regarded as alternative paths of outgo of chlorine.

The urinary elimination of phosphorus was usually less than 0.2 gm., but the high proportion of grain to roughage fed to Cows 3 and 4 in Period III, and a probable pathological condition of Cow 7, Period III, led to marked increase in urinary elimination of phosphorus, which may be regarded as an expression of acidosis.

The elimination of arsenic in the urine was remarkably uniform, the intake of this element being identical with each of the six cows.

DISCUSSION OF INDIVIDUAL BALANCES

Sodium.—Our arbitrary fixing of the sodium chloride intake, at seven-thousandths of the amount of the grain, resulted in the provision of an allowance which was, perhaps, hardly sufficient, since 7 out of the 18 sodium balances, and 3 out of the 18 chlorine balances were negative; but, except for the case of Cow 3, Period II, which was manifestly underfed, the maximum loss of sodium was 2.5 grams per day, and of chlorine 1.4 grams; and the gains were much more numerous and extensive than the losses.

In consideration of the extreme mobility of sodium (its pronounced susceptibility to influences of slight magnitude), and the size of the cow, not to mention the difficulty of estimating sodium with accuracy, we do not incline to emphasize the significance of a maximum loss of 2.5 grams of sodium per day; but to provide against the possibility of loss a larger intake might well be provided.

We incline to regard as more significant than any of the losses of sodium the positive balances of Cow 4, Period I, Cows 4, 7, 8, 9, and 10 in Period II, and Cows 7, 8, 9, and 10 in Period III, these positive balances, some large, some small, apparently resulted especially from a considerable intake, or low milk production, or advance in the period of gestation, or combinations of these influences which make for storage.

Comparing the sodium balances of Cows 3 and 4 in Period III, the loss of Cow 4, in spite of high intake, was in response to a general state of metabolism which caused losses of all elements studied, except nitrogen and arsenic. This condition was a high milk production, 61.36 pounds, on a ration which was insufficient in amount to support it.

The largest storage of sodium, 10.2 grams per day, occurred with Cow 7, Period II, in which case we had a combination of high sodium intake, low milk production, and lateness (7½ months) in the period of gestation.

Chlorine.—The three negative balances of chlorine appear to be due to the very high chlorine content of the first milk of a fresh cow (Cow 3, Period II), to very high milk yield (Cow 4, Period III), or to a very laxative diet (Cow 7, Period III). This last cow defecated, on an average, 12.4 times per day during the 16 days of this collection period. It was doubtful throughout this period whether this cow could be retained in the experiment.

Potassium.—Thirteen balances out of 18 of potassium were negative. These losses were largely in the urine, the proportion of the total outgo which was in the urine being 67.3 percent for cows in full milk, and 87.9 percent for cows which were dry or nearly dry. These negative balances of potassium were never equal to more than a small part of the amount of the potassium in the urine There was no suggestion, then, of deficient absorption of this element.

The five positive balances were all with cows which were dry or nearly dry, but not all of the dry or nearly dry cows stored potassium.

The sodium and potassium balances differed in 6 cases out of the 18, there being no marked tendency for these to vary together. In these six cases the sodium balances were always positive and the potassium negative.

The high urinary outgo, in all cases, including those in which the balance was negative, indicates that these losses were not due to actual insufficiency of the intake. We are unable with certainty to interpret them. They may possibly be due to unexplained interelemental relationships in metabolism, or to periodic fluctuations as yet undefined.

Calcium.—In this our fourth experiment on the same subject we have our first positive calcium balance. In this investigation 10 out of 18 balances are positive. In each of these 10 instances the cows were dry, or nearly dry. All of the cows which were dry or giving as little as 3.95 pounds of milk per day, and one giving 9.98 pounds, stored calcium. No others did so.

All cows in full milk, and one other, lost calcium. The maximum loss (Cow 5, Period I) was in a case of general underfeeding, the cow representing days 55 to 74 of lactation, and the balances all being negative with the exception of chlorine. The second and third largest losses were with Cows 4 and 3, Period III, representing days 24 to 33, and 30 to 39 of lactation, respectively.

In connection with our previous 40 balances, all negative, in spite of calcium intake varying from normal to excessive, all of the subjects being in full milk, this present evidence is of unmistakable significance and validity.

In dairy cows of good productive capacity parturition releases a flow of calcium in the milk which proceeds to such extent independently of the food supply of calcium that a loss of calcium from the body is normal, at least on rations composed of winter feeds, either dry or including corn silage, until such time that this impulse to secrete milk has largely spent itself. From the time that a cow's milk production has fallen to about 10 pounds, until she goes dry, and while she is dry, she can store calcium from rations of the types specified.

We were unable to prevent loss of calcium, during liberal lactation, by the feeding of calcium supplements, and neither was there any certain advantage resulting from so doing in any case, that is, whether the cows were milking or were dry.

In our judgment calcium balances are of very uncertain significance as indicating the sufficiency of the calcium intake. The normal loss of calcium during lactation is undoubtedly due to the elimination of calcium in the milk, but the calcium loss is not closely in accord with the extent of the outgo by this channel. This loss appears rather to be the resultant of many factors, among which are the degree of the impulse to secrete milk, the power of the cow to digest, absorb, and assimilate calcium, and the ability of the cow to draw upon her mineral reserves.

The calcium and phosphorus balances agreed as to sign (+ or —) in 15 balances out of the 18, in harmony with the obvious fact that the associated metabolism of this pair of elements is very much greater than their metabolism independent of each other.

It is worthy of note, and significant, that all of the 10 positive calcium balances are associated with positive nitrogen balances, and all of the four negative nitrogen balances are associated with negative calcium balances; that is, a state of metabolism involving nitrogen storage appears to be a favorable influence as affecting calcium retention, but in our earlier work we found that large nitrogen retention may occur coincident with calcium loss.

Magnesium.—Fifteen out of the 18 balances of magnesium were negative. These losses occurred mainly through the feces. Of the three positive magnesium balances all were associated with positive balances of both calcium and phosphorus, but there were six other instances of positive balance of calcium and phosphorus together, in which the magnesium balances were negative.

Thus, magnesium may be retained, when calcium and phosphorus are also retained, but in this experiment it was lost from the body more commonly than it was retained, under these conditions.

In seven out of 10 instances of positive balance of calcium there were negative balances of magnesium, but there were no cases of magnesium storage associated with calcium loss. These data raise the question as to whether those conditions which are favorable for calcium retention are to any degree unfavorable for magnesium storage.

Phosphorus.—Among the 18 phosphorus balances 11 were positive. As usual the metabolism of this element parallelled that of calcium; but also, as usual, there were exceptional instances which demonstrated their partial independence. Nine of the positive calcium balances were accompanied by phosphorus balances of the same sign.

One positive phosphorus balance (Cow 1, Period I) accompanied extensive milk secretion, in harmony with previous observations that the conditions necessary for phosphorus storage are more readily attainable than those necessary for calcium retention, probably by virtue of the more extensive metabolism of phosphorus in tissues other than the skeleton.

While the intake of phosphorus was in no case less than 25 grams there was normally less than half of a gram of phosphorus in the urine, though as much as 14.977 grams of phosphorus was eliminated in the milk, associated with a positive phosphorus balance, and 25.328 grams in a case in which the balance was negative.

In three instances (Cows 3, 4, and 7, Period III) the usual amount of phosphorus in the urine was much exceeded. With

Cows 3 and 4 this was apparently due to acidosis, caused by the high proportions of grain in the rations, resulting in relative deficiencies of mineral bases. In the case of Cow 7, the subsequent history of this individual suggests that the slight excess of phosphorus in the urine was due to functional derangement the nature of which was not determined.

Dr. Alfred F. Hess has called our attention to the seasonal tide in the inorganic phosphate of the blood of infants, an ebb in the winter and flood in the summer; and raises the question as to whether there is in the calcium and phosphorus metabolism of cattle an effect of sunlight such as he has demonstrated in the case of children suffering from rickets. It may be that the stimulus of summer sunshine is necessary to the efficient utilization of calcium and phosphorus by milch cows. This suggests a promising point for future research.

Sulphur and nitrogen.—Of sulphur 7 balances were negative and 11 positive; and of the nitrogen, 4 negative and 14 positive. Three of the four negative nitrogen balances were associated with negative sulphur balances, under circumstances signifying, clearly, underfeeding (Cows 2 and 5, Period I, and Cow 3, Period II).

The sulphur and nitrogen balances were of the same sign in 13 cases out of the 18. The three cases above mentioned, in which both sulphur and nitrogen balances were negative, were characterized by general mineral insufficiency. The conditions unfavorable to sulphur and nitrogen storage doubtless added an unfavorable influence as affecting the retention of the other elements studied.

The four negative sulphur balances which were accompanied by positive nitrogen balances signify, at face value, that the nitrogen intake was more commonly sufficient for maintenance of equilibrium than the sulphur intake. This evidence of independence in nitrogen and sulphur metabolism may be due to the facts that some nitrogenous structures, hair, for instance, are much richer in sulphur than others, and that there was a more rapid growth of hair in one cow than in another.

That the general metabolism of sulphur is organic, and associated with nitrogen in protein compounds, is manifest, the sulphate excretion signifying for the most part, surely, the elimination of a protein katabolite. The negative balances of sulphur seem to signify an intake insufficient to the demands of body repair, growth of the fetus, and milk production.

Arsenic.—Our main interest in the metabolism of arsenic was to determine if it would be eliminated in significant amounts in the milk. The balances of arsenic answer this question in the negative. No arsenic was found in the milk, except a trace (0.00004 gm. per day) in the abnormal lacteal secretion of a cow which was virtually dry and was not being regularly milked. During the 16-day balance period this cow was milked only four times, as the condition of the udder required.

The amount of arsenic administered was liberal dosage, 0.28784 gm. per day. So far as our evidence goes, then, the above amount of arsenic, fed to a cow, will not be eliminated in the milk in determinable amounts, but the fact that arsenic was retained in each case suggests that in a long-continued use of arsenic there might be an accumulation of this element in the tissues such as would be eliminated in significant amount in the milk; but this is only hypothesis. Experiments covering this point should be conducted. This apparent retention, however, may have been in part at least an undetermined elimination, as, for instance, by the skin.

Arsenic was eliminated in considerable amounts in both urine and feces, but, in all cases, in much larger amounts in the feces. The urinary outgo varied between 0.05566 and 0.0958 gm., the fecal outgo between 0.10223 and 0.15367 gm., and the retention between 0.047 and 0.124 gm.

We see no indication at all that arsenic is effective as a calcium tonic, that is, that it is conducive to calcium retention. This does not mean, however, that it might not have such an action in pathological conditions or in the metabolism of a growing animal.

Further light on the metabolism of arsenic by cows is furnished by the work of Bloemendal[11], and of Harkins and Swain[12].

Bloemendal cited many conflicting statements concerning arsenic metabolism, and reported on experiments of his own. He found that cows in a normal, healthy condition did not eliminate arsenic in their milk, so long as it was given them in amounts below the point of toxicity. However, cows which had been given non-toxic doses previous to calving eliminated traces in the milk immediately after calving.

Harkins and Swain showed, in connection with a study of arsenic poisoning of livestock, as a result of eating forage contaminated by smelter fumes, that in cases of chronic poisoning by arsenic this element is unmistakably eliminated in the milk.

---

[11]Bloemendal, W. H, Arch. der Pharmacie 246 (1908), 599-616.
[12]Harkins, W. D. and Swain, R. E, Journ Am. Chem Soc, 30 (1908), 915-946.

THE UTILIZATION AND ELIMINATION OF NITROGEN

In considering the use of nitrogen by the cow we may think of the feces nitrogen (minus the metabolic fraction, which we have no accurate means of estimating) as the indigestible portion, and the urine nitrogen (plus fecal metabolic nitrogen) as representing the digestible nitrogen required for body repair. These two fractions, subtracted from the food nitrogen, leave that portion which is utilized for milk production and for the upbuilding of the body, that is, for constructive purposes aside from, or in excess of, repair.

The proportion thus utilized is reported in the fourth column of figures in Table XIII, page 57. It is obvious that a close comparison of these figures, as indicating the value of the nitrogen of the several rations, or the effects of the mineral supplements upon nitrogen metabolism, would require that each cow be fed the same amount of nitrogen in relation not only to the maintenance requirement but also to the productive capacity of the individual. It is not practicable to control the nitrogen intake with this particularity in metabolism experiments with cows, since the necessary experimental conditions are in many ways so difficult to maintain that many compromises with the desires of the experimenter are inevitable. This general situation will be borne in mind in the interpretation of the data in this table.

Cows 3 and 4 utilized larger amounts and proportions of the nitrogen of the ration in Period III, while they were producing milk, than in Period I, while they were dry, the nitrogen intake being increased in Period III, but the nitrogen in the urine remaining about the same.

Cows 9 and 10 excreted more nitrogen in the urine after going dry (Period III) than just before (Period II), though the nitrogen of the ration was decreased.

The proportion of the nitrogen intake appearing in the feces is comparatively uniform, the only prominent departure from the prevailing order being in the case of Cow 8, Period III, covering the last 7 days in the period of gestation, in which balance the high fecal elimination of all of the elements suggests that the approach of parturition, either through leading to greater activity, as in frequent getting up and lying down, or otherwise, led to an abnormal elimination of feces. If this hypothesis is true the facts would tend to reduce positive and to increase negative balances.

The utilized nitrogen, by which we mean the nitrogen of the milk plus the positive or minus the negative balances, shows that the nitrogen intake was not closely in accord with the need.

In Period I the milking cows eliminated a much lower proportion of the nitrogen of the ration in the urine than did the dry cows. The same is true in Period III. In Period II the large proportionate elimination of nitrogen in the urine of Cow 3 is due to the exceptional conditions existing, in that the subject was a fresh cow, the collection period beginning immediately after parturition, and in that the cow was underfed. Aside from this instance the proportion of the food nitrogen eliminated in the urine was comparatively uniform, in harmony with relatively uniform conditions as to milk production.

COEFFICIENT OF DIGESTIBILITY OF RATIONS

The coefficients of digestibility of the rations are recorded in Table XIV, page 58. The average digestibility of protein was 66.23 percent, of nitrogen-free extract 78.64 percent, of ether extract 65.02 percent and of crude fiber 36.33 percent.

The coefficient for protein seems very low. This would have been higher, and more nearly a true figure, if we had been able to estimate the metabolic nitrogen. There is no significant method for estimation of metabolic nitrogen in feces. These figures represent apparent rather than real digestibility of protein.

That the coefficient for ether extract was still lower than that for protein is due mostly to the fact that the ether extract of these rations did not represent at all closely their true fat content. This error is known to apply especially to the use of ether extract as a measure of the fat content of roughage.

With reference also to nitrogen-free extract, the coefficient of digestibility suggests the fact that nitrogen-free extract is a very crude conception, as representing starch, sugar, and related substances of similar nutritive values.

In fact, our present use of digestion coefficients stands in urgent need of being placed on a new and greatly improved basis of significance.

No connection has been demonstrated between the mineral content and the digestibility of the rations fed, and no such relation is considered likely, short of the point at which the "salt-action" of the mineral compounds in the alimentary tract would result in the hastening of the elimination of the food residues, with the lowering of apparent digestibility.

Among individual variations in digestion coefficients the records on Cow 8 are noteworthy. As previously noted, in other connections, the apparent inefficiency of the digestion of this cow may have been due only to the effects of parturition, which was imminent. Increased activity, and restlessness, may have led to the elimination of greater amounts of feed residues than were derived from the feed of the balance period, thus serving improperly to lower the digestion coefficients.

The nutritive ratio of the several rations varied to some extent. These differences may be considerd as the result of necessary concessions to the individuality of the subjects, as manifested in their attitude toward the feed. In order to have the cooperation of the cow, without reservation, it is necessary to adjust rations to suit peculiarities of appetite and digestive capacity.

DISTRIBUTION OF OUTGO AMONG MILK, URINE, AND FECES

Sodium.—Of the outgoing sodium a maximum of 57.7 percent was eliminated in the milk of a fresh cow (days 1 to 7 of lactation). The urinary excretion varied between 15.4 percent (days 30 to 39 of lactation) and 76.2 percent (a dry cow). The fecal sodium varied between 9.8 percent (days 1 to 7 of lactation) and 83.5 (a dry cow). The fecal excretion of sodium was high in Period III in which Fowler's solution of arsenic was administered.

Potassium.—The intake of potassium was not much affected by the potassium content of the Fowler's solution, but was determined most largely by the amount of alfalfa hay eaten. The maximum percentage of potassium outgo in the milk was 31.8 (days 30 to 39 of lactation). In the urine the range of variation was between 49.6 percent (days 30 to 39 of lactation) and 95.1 percent (a dry cow); and in the feces, between 4.9 percent and 20.9 percent (both dry cows).

Calcium.—The outgo of calcium in the milk reached a maximum of 34.8 percent of the total outgo (days 1 to 7 of lactation). The variation in the urine was between the narrow limits of 0.1 and 1.5 percent, and in the feces between 65.1 percent (days 1 to 7 of lactation) and 99.9 percent (a dry cow).

Magnesium.—As much as 14.6 percent of the outgoing magnesium was eliminated in the milk (days 1 to 7 of lactation), while the range in the urine was between 6.8 percent (days 24 to 33 of lactation) and 22.0 percent (a dry cow); and in the feces, between 76.5 percent (days 1 to 7 of lactation) and 91.4 percent (a dry cow).

Sulphur.—The maximum proportion of the outgoing sulphur in the milk was 42.7 percent (days 1 to 7 of lactation). In the urine the outgo varied between 30.9 percent (days 1 to 7 of lactation) and 55.9 percent (a dry cow); while in the feces the variation was virtually the same, between 26.3 percent (days 1 to 7 of lactation) and 56.5 percent (a dry cow).

Chlorine.—Chlorine was eliminated in the milk in quantities reaching 84.1 percent of the outgo (days 1 to 7); in the urine the elimination varied between 3.2 percent (days 1 to 7 of lactation) and 75.1 percent (a dry cow); while in the feces the elimination varied between 12.7 percent (days 1 to 7 of lactation) and 54.5 percent (a dry cow).

Phosphorus.—The milk contained a maximum of 61.2 percent of the outgoing phosphorus (days 1 to 7); the variation in the urine was between 0.2 percent (days 55 to 74) and 6.0 percent (days 30 to 39), and in the feces, between 38.5 percent (days 1 to 7) and 99.5 (a dry cow).

Arsenic.—No arsenic was eliminated in the milk. In the urine the outgo was 31.1 to 46.8 percent, and in the feces between 53.2 percent and 65.9 percent (all dry cows).

Nitrogen.—Nitrogen was eliminated in the milk in amounts as high as 52.5 percent of the outgo, but the highest proportion of the outgo in the milk, coincident with nitrogen retention, was 35.3 percent. The retention in this case was 5.917 grams, which was 1.7 percent of the intake. The outgo in the urine varied between 29.4 percent (days 24 to 33) and 65.5 percent (a dry cow), while the outgo in the feces varied between 15.9 percent (days 1 to 7) and 49.2 percent (a dry cow). The minimum proportion of the outgo in the feces was associated with a negative nitrogen balance equivalent to 83 percent of the intake. This low fecal outgo, then, signified underfeeding.

The elimination of minerals in the urine appears to be much affected by the amount of milk produced, that is, material which is eliminated in the urine of the dry cow may be deflected, in large part, to the milk, during the period of lactation.

The circumstances which determine path of outgo from the body may be quite without bearing on the matter of retention; thus, the outgo of sodium, potassium or magnesium may be deflected from urine to feces or from feces to urine, in considerable measure, without this involving the status of the body reserves in any degree.

DISCUSSION OF RESULTS

The most important addition to our knowledge of the mineral metabolism of the milch cow which is contributed by this experiment is that under the same conditions as to feeding, care, and experimental routine as have resulted, in this series of studies, in 49 negative balances of calcium during the liberal milk production of the first half of the period of lactation, without one exception, the subjects of this last experiment stored calcium as soon as the milk production had decreased to such extent that the calcium outgo did not exceed their capacities to assimilate calcium, and also, invariably, when they had ceased to produce milk.

The exact point in the shrinkage of the milk flow at which it became possible for a cow to store calcium was not determined, but we are prepared to learn that it is above rather than below the production of 10 pounds of milk per day.

In the light of the results of our four studies on this subject, which cover, in a more or less continuous series of observations, the whole of the annual cycle of lactation and gestation, we are able to depict the calcium metabolism of a year in the life of a producing cow in the following terms:

Parturition turns loose a pent-up flood of nutriment which has been stored for the growth of the calf. This outpouring of mineral-rich food proceeds in large measure independently of the food supply; that is, if the food is sufficient to maintain the life of the cow she will produce milk even though this involves extensive drafts upon the tissues of the body.

This impulse to secrete milk has been greatly intensified by selective breeding. We have to do, therefore, not alone with Nature's adjustments, but especially with the effects of Man's interference with Nature by the creation within the cow of an impulse to produce very much more milk than does the cow as Nature made her.

Now, in intensifying this tendency, we have developed the power of the cow to draw upon the nutrient stores which compose her own tissues to such an extent that the results are often matters not only of practical importance but also of serious concern.

At some point between the middle and the end of the period of lactation, when the impulse to secrete milk has largely spent itself, the milk production comes to be more definitely related to and dependent upon the feed intake, and falls off, in amount, to such extent that retention of calcium, the dominant factor of the whole mineral system, comes to prevail.

In the mean time the cow has been bred. The demand of the fetus for mineral substance is slight, in the light of the capacity of the cow to metabolize mineral substance in the elaboration of milk. True, toward the end of the period of gestation the fetus increases greatly its appropriation of mineral substance, but this factor remains a minor one in the mineral metabolism of the cow.

In the unimproved cow lactation ceases when the calf is weaned, long before the end of the next period of gestation, but with many cows of improved breeding the milk production may persist quite to the time of parturition, and the history of cattle breeding embraces accounts of cows which have produced milk for several years after the birth of a calf.

The more successful breeders have learned, however, that the feeding and management of the highly developed milch cow during the latter part of the period of gestation is a matter of critical importance, and it is in this connection that the results of this experiment are of greatest interest.

Our findings and the most successful practice both indicate that a cow must have a dry, resting period of sufficient length to permit the entire replacement of the preceding mineral overdraft, if the vitality, fecundity, and productiveness of the cow are to remain unimpaired; and to this end it is desirable that the dry cow be fed as liberally as practicable, without undue risk of milk fever subsequent to the following parturition.

We have encountered, among practical dairymen, a belief that certain feeds stimulate milk secretion to an extent which they are inadequate to sustain. Alfalfa hay is said to have such a tendency. This may be true in the sense that if the alfalfa is consumed liberally and is not accompanied by adequate amounts of carbohydrate nutriment its proteins may stimulate the cow to produce milk at the expense of a heavy draft upon the body fat. Thus, the more liberal the feeding of alfalfa hay the heavier might be the milk production, with increasing emaciation of the cow.

A possible instance of such a situation is to be seen in the performance of Cows 3 and 4, Period III (see data below). Reference to Table XII, page 56, will show that these cows stored small amounts of nitrogen, but that the mineral balances were nearly all negative; and reference to Table III, page 47, shows that both cows were losing in weight. At the same time the milk production of Cow 3 increased continuously, while Cow 4 increased to her maximum and then began to recede. These balances covered days of lactation 30 to 39 and 24 to 33, respectively. It is conceivable that the nitrogenous components of the ration exerted an activating or stimulating influence as affecting milk yield.

Daily Milk Yields of Cow 3 and Cow 4 in Period III (Grams)

Date	Cow 3	Cow 4
Mar. 23	23755	26960
24	24529	27627
25	24312	27745
26	24073	28525
27	24330	27890
28	24944	27894
29	24975	28820
30	25284	27873
31	25279	27554
April 1	25597	27441

Meigs, Blatherwick, and Cary[13] after discussing our previous results in connection with like data announced the conclusion that

"The separate collection of urine and feces by attendants, as practiced in balance experiments on cows, produces a nervous disturbance in the animals which interferes markedly with the assimilation of calcium, and, to a less degree, with that of nitrogen and phosphorus."

We understand that the gains and losses of calcium and other mineral elements could not prevail indefinitely in the same relative amounts, one to another, as observed in some instances in this investigation; and also that the retention of calcium by cows under conditions of practice must be more extensive than as observed in our experiments, but we hesitate to ascribe these conditions to the cause assumed by Meigs and associates since we are without evidence as to the effect of any specific influence, of the sort suggested, on calcium metabolism, and since there was no evidence of nervous disturbance in our experimental subjects.

Hart and associates[14] showed that lactating goats made more efficient utilization of the calcium of the ration if the roughage was fresh, green oat plant than if it was dry oat straw, the balances of calcium, however, remaining negative.

The senior author of this paper has reported observations[15] on a group of cows at the Ohio Agricultural Experiment Station, which have an important bearing on the subject of calcium metabolism.

Since the year 1911 this group of cows has been maintained on dry feeds alone, under the management of Mr. C. C. Hayden.

[13]Meigs, E. B., Blatherwick, N. R., and Cary, C. A., Journ. Biol. Chem., 40 (1919), 469.

[14]Hart, E. B., Steenbock, H. and Hoppert, C. A., Journ. Biol. Chem., 48 (1921), 33-50, and Science, 52 (1920), 318.

[15]Forbes, E. B., Science, 52 (1920), 467-468.

Several of these individuals were born and raised to maturity without having had a bite of green feed. Quoting from our published observations on these dry-fed cows:

"This group of cows has grown to normal weights, and has produced and reared calves without marked or certain irregularity or abnormality. The milk production has been fair only, it being obvious that with normal treatment these cows would have given more milk. They do not have normally keen appetites and some are easily forced off feed. They will not eat enough feed to support maximum milk production. They fall away during lactation a little more than is customary, but pick up again after going dry. These cows have been in noticeably less thrifty condition, as indicated by flesh and coats, than the balance of the herd, which goes to pasture, and it has been apparent that they crave something which they do not find in the ration".

"It appears, therefore, that the suggestion of Hart and associates is a matter of practical importance as relating to milk production, but that rations of dry feeds and silage, though probably deficient in some constituent, are not entirely lacking in any essential."

They ate steamed bone with avidity, and were probably in a state of mineral depletion.

In the light of the work of Hart, with goats, and our observations on the group of dry-fed cows at the Ohio Station, it seems to us likely that shortage of pasture, and, therefore, of the "fresh-grass vitamine", rather than shortage of calcium and phosphorus, is the factor accountable for the unusual annual decrease in the yield of the cows of the main herd at the Beltsville Farm of the Department of Agriculture, as reported on by Meigs and Woodward[16]. These cows are said to have "little or no pasture". Their response to phosphate feeding, and to a prolonged dry period, seems phenomenal. It appears that these cows are comparable, in condition, to the dry-fed group at the Ohio Station, and that the conclusions of Meigs and Woodward as to the efficacy of feeding sodium phosphate and the alternate feeding of grain and forage, on separate days, apply rather to cows which are suffering from the effects of lack of pasture than to cows in general.

The difference between winter roughage and fresh, green forage, then, in the light of our present incomplete understanding. seems to be a secondary factor in the complex which causes fresh cows on winter rations to draw on their mineral reserves for calcium, the most important causes being the exaggerated impulse of

[16]Meigs, E. B., and Woodward, T. E., Bul. 945, U. S. Dept. Agr., May 1, 1921.

the improved cow to secrete milk, and her limited ability to assimilate calcium. The ultimate cause of this limited ability to assimilate calcium has not been determined.

As indicating the possibilities of calcium storage, on dry winter rations, without silage, we cite the case of Cow 4, Period II, page 55. This dry cow stored 14 grams of calcium per day. The maximum amount of calcium eliminated in the milk, in this experiment, with this same cow, in Period III, after calving, was 29.4 grams, the cow producing 61.36 pounds of milk, with a negative balance of 12.3 grams of calcium, the apparent assimilation of calcium from the ration being 17.1 grams.

The possibilities of calcium retention and calcium utilization in the elaboration of milk, therefore, appear to be of similar magnitude. The storage in the first case exceeded the negative balance in the second. It would appear, then, that a dry cow can store calcium at a rate not unlike the most that she is apt to lose during heavy milk production on a good ration.

Two facts with reference to the utilization of calcium by the cow stand out with great prominence, first that the cow's ability to assimilate calcium from winter rations, either with or without the addition of organic or inorganic supplements, is more definitely limited than is her ability to assimilate other nutrients; and second, that the freedom with which cows can draw upon the calcium of their own bones, and the extent of this draft in cases in which it is necessary, shows that, at least for the satisfaction of requirements above a certain amount, the calcium of the skeleton is more readily available than is that of winter rations and calcium supplements fed in the usual way.

In regard to this whole matter of negative calcium balances in milking cows, this situation is perhaps a little more readily understandable if considered as related to the localized withdrawal of mineral salts from bone during pregnancy. The main facts as to this phenomenon are understood in connection with human physiology, in which the bone dissolution sometimes involves the teeth; and, in rare instances, the mineral disorganization proceeds even to the production of osteomalacia, which has been regarded, in this connection, as an uncontrolled accentuation of the normal osteoclastic changes of pregnancy.

In such an investigation as this which we discuss, one is puzzled by the appearance of negative balances which can not possibly signify insufficiency in the supply of the nutrients in question. It is obvious that negative balances do not always have the same signification. In an effort to assist in the solution of the problem of these negative balances we suggest the following possibilities:

Negative balances may be due to deficiency in the supply of the nutrient; they may also be determined by negative balances of other elements or compounds, organic or inorganic (including vitamines), which are necessary to the utilization of the element in question; they may be periodic fluctuations, connected with the reproductive cycle, which would be revealed as such by the accounting for the nutrient in question during the whole of this period, the causes, therefore, lying entirely outside the ration; they may be fluctuations in extensive reserves, especially of the more highly mobile elements, in response to physiological antagonisms, or "oppositeness" of function, in cases where excessive intake is to be disposed of, or where unusually extensive utilization involves abundant transfers; they may be due to inherited demands for the mobilization of greater amounts of a nutrient than the organism is able to digest or to assimilate, as in milk production, thus demanding drafts upon the reserves of the body.

The interpretation of a negative balance, then, may be a matter of some uncertainty, presenting opportunity for the exercise of judgment and the possibility of error.

INTERRELATIONSHIPS OF ELEMENTS IN METABOLISM

As a general background against which to consider the observations made regarding interrelationships among the mineral elements, and between them and nitrogen, we may consider that while we have, in the ration, inorganic compounds in various states of combination and solubility, the compounds presented to the intestinal epithelium at any particular time, for absorption, comprise a very different grouping of acid and basic elements.

As the mineral elements of the ration go into solution in the alimentary tract the following processes come into action, (1) a factor of change in the direction of a larger representation of the less readily soluble compounds, (2) a tendency to molecular rearrangement of ions, in the direction of chemical equilibrium, and (3) absorption of mineral substances from the alimentary tract, and return to the same, either as excreta or as components of digestive secretions, in a great complexity of relations in the several regions of the alimentary tract.

These conditions determine the facts that the combination of compounds presented the intestinal epithelium, for absorption, is not the same as contained in the ration, but is a changed and a constantly changing one, and that since we have no means of disinguishing, in the feces, between unabsorbed minerals and others which have been absorbed and returned to the intestine, it becomes very difficult to trace the fate of any particular mineral component of the ration through all of its changes of relationship to its final disposal.

Then when we add to this picture the conception that the rate of absorption of the several elements from the intestine must differ, for each, as determined in part by the capacity of the organism to remove each of them from the bloodstream, by synthesis, precipitation, or excretion, we have before us the outline of a complicated situation, the details of which are for the present beyond us.

Aside from the marked independence existing, among the minerals, in metabolism, the most prominent of the facts as to the interrelationships of the elements are those relating to the minerals on the one hand, and nitrogen and organic sulphur on the other.

In harmony with the extent of the fluctuations which there may be in the so-called "circulatory protein", and the readiness with which these may be brought about, and also the fact that nitrogen equilibrium may be maintained on various levels of intake, are our observations that nitrogen and sulphur storage in the lactating cow may be rather easily accomplished by ordinarily liberal feeding.

At the same time it is manifest that the metabolism of the minerals is on a distinctly different basis. There is not the same elasticity either as to planes of metabolism or as to functional interchangeability that there is among the organic nutrients. The mineral requirements are relatively fixed, and the mineral nutrients needed in largest quantities are relatively difficult of digestibility and assimilability.

The interdependence of protein and mineral metabolism appears to be remote. In the long run this interdependence must be essential, —absolute, but the mineral reserves are so extensive that we see little evidence of this in either experimental or practical feeding.

In connection with the apparently considerable measure of independence in the metabolism of calcium and phosphorus it is of interest to note the variation which there may be in the composition of the bones of swine. Forbes and associates[17] have demonstrated that, under the influence of various calcium compounds and preparations, fed as supplements to a standard ration, appreciable though limited change in the relative amounts of the component mineral elements in bone can be produced. Similar variation is doubtless possible in the skeletons of cows. We are not of the opinion, however, that such changes could result in extensive alterations in the proportions of the mineral elements of bone.

Numerous observations of a superficial nature have been made in this paper and in the earlier numbers of this series, regarding the interrelations of the minerals, but the conditions of the experiments have not been favorable for positive demonstrations. The definite establishment of the details must await experiments so planned that the proportions between the mineral elements of interest are the only variants.

PRACTICAL BEARINGS

The practical significance of this subject of the mineral metabolism of the cow lies in the fact that milk production, on winter rations, involves considerable drafts upon the mineral substance of the skeleton.

In connection with the behavior of cows are a number of situations in which this mineral depletion may play a significant role.

The circumstances referred to, which we are inclined to associate with the mineral losses found to prevail in milk production, are (1) that there is greater difficulty in getting a cow with calf after heavy and prolonged lactation than earlier in the period, (2) that cows bred too young tend strongly to remain permanently small, (3) that an occasional cow will fail, unaccountably, after calving, to approach her normal milk production, (4) that cows calving while in especially thin condition, or calving without having had a dry, resting period, are likely to begin the lactation at less than the normal rate, or, after a brief term of production, to fail abruptly, and (5) that performance tests of milch cows, under conditions of forced production, have resulted in the loss of breeding capacity of so many superior cows as to occasion frequent comment and discussion among dairy cattle breeders.

Meigs and Woodward[18] have reported detailed observations on the behavior of cows, in this relation, which are of the greatest interest and value.

---

[17] Forbes, E. B., and associates, Ohio Agr. Exp. Sta. Bul. 347, p. 69-77, 81.
[18] U. S. Dept. Agriculture, Bul. 945, May, 1921.

Whatever the extent of the part played by mineral depletion in the production of these states of functional derangement it is obvious that the maintenance of maximum productive activity requires that the mineral overdrafts occurring during the early part of the period of gestation must be repaid.

This restoration of mineral reserves occurs during the latter part of the period of lactation, and especially during the dry period, and requires that the ration be at least moderately rich in mineral nutrients, especially calcium and phosphorus.

The advantage to be derived from the feeding of mineral supplements seems to us doubtful, but it is so easy to provide minerals in this form that the possibilities of benefit from so doing should be thoroughly investigated, under conditions of practice, not only during winter feeding but also during the season of pasturing.

The results of this investigation emphasize the necessity of a dry, resting period. The feeding during this time should be sufficiently liberal to permit the building up of extensive reserves of nutriment which shall protect the vitality of the cow and permit the full expression of her capacity to produce milk during the following period of lactation.

Provisionally we recommend, in harmony with the suggestions of Meigs and Woodward, liberal feeding during a dry period of four to six weeks for cows in a normal state of nutrition, and eight weeks or more for cows in a state of depletion; also that during this period cows should be fed two to three times the amount of total nutriment and three to four times the amount of protein necessary for maintenance.

The primary opportunity for building up the nutrient reserves of the cow is during the growth of the heifer. Dairymen have debated the question as to the wisdom of liberal feeding during this period, with the preponderance of sentiment in the affirmative. The facts as to the mineral metabolism of the cow suggest the great desirability of making the most of the storage or constructive possibilities of the animal at this time.

In our experimental work the calcium balances have been determined by the functional activity of the cow rather than by the calcium compounds offered in the ration. No basis was developed for the preference of one calcium supplement to another. On presumptive evidence alone, then, we suggest, for practical experimental purposes, the feeding of calcium phosphate in the form of steamed bone.

Steamed bone for feeding purposes should be promptly dried, and specially handled in a way to make it safe and acceptable; and, to facilitate its solution in the digestive secretions, it should be finely ground, preferably through a twenty-mesh screen. Cows will eat fertilizer bone, but, in consideration of the methods by which it is ordinarily produced and handled, we do not recommend it as a feeding-stuff.

Cattle will take steamed bone readily, either mixed with the feed, or offered at free will mixed with one-fourth as much common salt. From two to six ounces per day appear to be reasonable amounts to feed.

We have not tested the ideas of Meigs and associates, that sodium phosphate is a more effective mineral supplement than calcium phosphate, and that the alternate feeding of grain and roughage on separate days (the phosphate being fed with the grain) is especially conducive to calcium and phosphorus retention, but we have shown that, under the conditions of a metabolism investigation, a dry cow stored as much as 14 grams of calcium per day without the provision of sodium phosphate or the practice of the system of alternate feeding.

A question raised by this investigation and Hart's observations on milch goats is as to the ability of a cow, in full milk flow, to maintain calcium equilibrium during the improved conditions for calcium utilization which prevail while she receives green feed. We anticipate an affirmative answer to this question, at least for cows of moderate productive capacity.

The results of this investigation apply, in a practical way, more to the dry-fed cow than to the cow at pasture, and more in regard to matters of management and feeding together than to feeding alone.

As for the bearing of this investigation on the feeding of cows suffering from actual mineral shortage in the ration, the facts as we have demonstrated them emphasize the seriousness of such a shortage, but unfortunately we have little evidence as to the conditions under which such actual shortage prevails. By informal observation we understand that deficient supplies of minerals in the rations of cattle do prevail during certain more or less unusual conditions as to components of the ration and as to soil and season, but this knowledge is indefinite, and does not tell us what we need most to know, that is, whether rations of grain and gramineous roughage can supply the full requirement of the cow for minerals, or whether a certain proportion of leguminous roughage is necessary for best results. The final clarification of these points will require metabolism investigations with green forage of gramineous and also of leguminous origin.

Other practical bearings of this subject are discussed in the preceding paper of this series[19], the point of view being that our chief concern in feeding practice is not so much to avoid definitely pathological conditions as to attain the maximum of efficiency, and that in the exigencies of practice the slight losses of minerals observed under the optimum conditions of our experimental work may be magnified, by unfavorable conditions, into considerations of importance.

It is also suggested that the skeletons of animals constitute their principal mineral nutrient reserves; that the skeletal development is dependent on the forage, since grains are very deficient in calcium; that the mineral content of the forage varies widely in accord with the natural composition or artificial fertilization of the soil; that there are seasonal effects on the mineral nutrients of the forage; that food shortage, deficiency of mineral nutrients in the forage, and other hardships, may react unfavorably on the mineral nutrient reserves, in this way becoming contributory causes of sterility, abortion, and malnutrition of the bones; and, finally, the specific bearings of the whole subject on general farm practice, especially as favoring the production of legumes, are pointed out.

SUMMARY

Calcium being the most abundant mineral element in the animal body, and its compounds relatively difficult of solubility, it dominates, in a sense, the mineral metabolism in general. Conditions as to its metabolism largely determine the utilization of the other mineral elements.

The calcium metabolism of the milch cow is characterized by rapid loss from the body during the early part of the period of lactation, changing to retention late in the period of lactation, by continued retention during the dry period, with most rapid storage at the end of the period of gestation.

The principal factors determining the loss of calcium during the early part of the period of lactation are the impulse to secrete milk, as accentuated by selective breeding, and a limited ability to assimilate calcium.

[19]Ohio Agr. Exp. Sta. Bul. 330, pp. 111-118.

In the course of this investigation there were 49 negative calcium balances, without one exception, during liberal milk production. The largest milk production with which there was calcium retention was 9.98 pounds. It is considered likely that calcium retention can occur during more extensive milk production.

The dry cow, on dry feeds, can store calcium at a similar rate to that at which the fresh cow, on dry feeds, loses calcium.

The loss of calcium from the body appears to be a prominent factor in the nutritive depletion and the functional derangement of the overtaxed milch cow.

The ability of a cow to assimilate calcium is much more definitely limited than her ability to assimilate nitrogen.

The calcium of the bones is more readily available, for purposes of milk elaboration, than the calcium of the ration and of mineral supplements.

It is not clear that supplemental calcium, added to normal rations, is utilized, either during lactation or during the dry period.

There was no evidence of a tonic effect of Fowler's solution in relation to calcium or other mineral retention.

A marked but not complete interdependence of calcium and phosphorus in metabolism was manifest. Phosphorus may be stored during liberal milk production; calcium seems never to be stored under these conditions, at least on winter rations.

In explanation of the observed partial independence of calcium and phosphorus in metabolism data are cited exhibiting the variability in the composition of the skeleton. The phosphorus of the tissues other than the skeleton may also be metabolized independently of calcium.

A positive nitrogen balance probably favors calcium retention, to a slight extent, but the measure of independence existing in the metabolism of nitrogen and the mineral elements is prominent.

There is a prominent but not a complete interpendence of nitrogen and sulphur in metabolism.

The utilization of the nitrogen of the ration, by the lactating cow, is more efficient than by the dry cow if the latter is allowed, as usual in practice, an amount of protein in excess of the actual maintenance requirement.

The average apparent digestibility of the protein of the experimental rations was 66.23 percent, of the nitrogen-free extract 78.64 percent, of the ether extract 65.02 percent, and of the crude fiber 36.33 percent.

Detailed data are presented indicating the distribution of the outgo of the mineral elements among milk, urine, and feces. The proportionate elimination by urine and feces bears no particular relation to mineral balances. Many negative mineral balances were determined which could not signify insufficient intake.

Five possible interpretations of the significance of negative balances of mineral elements are suggested (page 38).

The composition of milk including the colostrum suggests that its laxative character is due to physiological "salt action".

The milk of the cow was found not to contain arsenic, during the administration of 0.28784 gram of the element per day, in the form of Fowler's solution.

The milk toward the end of the period of lactation was found to differ from that of the middle of this period by being richer in nitrogen and in all of the minerals except potassium, which was distinctly low. Sodium and chlorine were in greatest excess.

Calcium was eliminated in the urine in the smallest amount by the freshest cows.

Chlorine excretion in the urine was low in the milking cows and high in the dry cows.

A high proportion of grain in the ration produced a marked increase in the urinary outgo of phosphorus, apparently as an expression of acidosis.

The physiological antagonism of sodium and potassium, and of calcium and magnesium is not discernible in the metabolism of practical rations and the considerable variety of mineral supplements used in this investigation (including the three previous studies).

The results of this investigation suggest the desirability of building up extensive mineral reserves in growing heifers by liberal allowance of feeds rich in mineral nutrients; and also the importance of a dry, resting period of adequate length to permit the restoration of all previous nutrient overdrafts, with liberal feeding during this period.

Note: Recent articles by E B. Hart and associates (Journ Biol. Chem, July and Sept, 1922) throw additional light on this subject by contributing further evidence of the existence in green alfalfa, and in alfalfa hay cured under caps, of at least a greater amount of some principle, probably a vitamine, which favors calcium assimilation, than is present in alfalfa hay cured in sunlight.

The hay used in our experiment was not cured under caps. It is not necessary, then, that hay be cured under caps in order to permit considerable calcium storage late in the period of lactation and during the dry period.

TABLE I.—STAGES OF LACTATION AND GESTATION COVERED BY THE EXPERIMENT

Period No.	Cow No.	Distinguishing feature of treatment	Period of lactation	Period of gestation	Average daily milk
					Pounds
1	1	Calcium supplement	139–158 day	49–68 day	42 77
1	2	No supplement	142-161 day	Not bred	37.87
1	3	Calcium supplement	Dry	246–265 day	Dry
1	4	No supplement	Dry	240–259 day	Dry
1	5	Calcium supplement	55–74 day	Not bred	40.63
1	6	No supplement	50–69 day	Not bred	49.61
2	3	No supplement	1–7 day	Not bred	47.48
2	4	Calcium supplement	Dry	275–279 day	Dry
2	7	Calcium supplement	Nearly dry	226–229 day	9.79
2	8	No supplement	Dry............	248–263 day	Dry
2	9	Calcium supplement	Nearly dry	182–197 day	3.95
2	10	No supplement	Nearly dry	178–193 day	9.98
3	3	Arsenic; no calcium	30–39 day	Not bred	54.47
3	4	Arsenic and calcium	24–33 day	Not bred	61.36
3	7	Arsenic and calcium	Nearly dry	250–265 day	1.28
3	8	Arsenic; no calcium	Dry	273–279 day	Dry
3	9	Arsenic and calcium	Dry	209–221 day	Dry
3	10	Arsenic; no calcium	Dry	202–217 day	Dry

Note:—All days indicated are inclusive; that is, the period from the 49th to the 68th day includes both of these days, and is 20 days long.

TABLE II.—ENUMERATION OF INDIVIDUAL BALANCE PERIODS, WITH DESIGNATION OF STAGES OF LACTATION AND GESTATION TO CORRESPOND, ARRANGED IN NATURAL SEQUENCE

Period No.	Cow No.	Distinguishing feature of treatment	Period of lactation	Period of gestation	Average daily milk
					Pounds
2	3	No supplement	1–7 day	Not bred	47.48
3	4	Arsenic and calcium	24–33 day	Not bred	61.36
3	3	Arsenic	30–39 day	Not bred	54.47
1	6	No supplement	50–69 day	Not bred	49.61
1	5	Calcium supplement	55–74 day	Not bred	40.63
1	1	Calcium supplement	139–158 day	49–68 day	42.77
1	2	No supplement	142–161 day	Not bred	37.87
2	10	No supplement	Nearly dry	178–193 day	9.98
2	9	Calcium supplement	Nearly dry	182–197 day	3.95
3	10	Arsenic	Dry	202–217 day	Dry
3	9	Arsenic and calcium	Dry	209–221 day	Dry
2	7	Calcium supplement	Nearly dry	226–229 day	9.79
1	4	No supplement	Dry	240–259 day	Dry
2	8	No supplement	Dry	248–263 day	Dry
1	3	Calcium supplement	Dry	246–265 day	Dry
3	7	Arsenic and calcium	Nearly dry	250–265 day	1.28
3	8	Arsenic	Dry	273–279 day	Dry
2	4	Calcium supplement	Dry	275–279 day	Dry

TABLE III.—AVERAGE DAILY FEEDS CONSUMED, MILK PRODUCED, AND GAIN OR LOSS IN LIVE WEIGHT

Cow No. and days in period		Feeds consumed: Corn	Cottonseed meal	Linseed oilmeal	Wheat bran	Alfalfa hay	Sodium chloride	Precip. bone flour	Precip. calcium carbonate	Fowler's solution	Milk produced	Average daily live weight	Average daily gain or loss in weight
PERIOD I		*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*C. C.*	*Grams*	*Kilos*	*Kilos*
1	20	5,161.0	397.0	397.0	397.0	7,720	44.452	54.9756	54.9756	....	19,400	501	—0.43
2	20	4,790.5	368.5	368.5	368.5	7,720	41.277	....	....	....	17,180	531	—0.89
3	20	2,947.8	226.8	226.8	226.8	5,448	25.401	61.5684	61.5684	....	....	588	+0.89
4	20	2,947.8	226.8	226.8	226.8	5,448	25.401	....	....	....	....	579	+0.17
5	20	4,790.5	368.5	368.5	368.5	7,720	41.277	47.1088	47.1088	....	18,430	440	+0.43
6	20	5,161.0	397.0	397.0	397.0	8,172	44.452	....	....	....	22,505	448	+0.33
PERIOD II													
3	7	2,951.0	227.0	227.0	227.0	5,448	25.424	....	....	....	21,537	519	—7.08*
4	5	2,951.0	227.0	227.0	227.0	5,448	25.424	62.7380	62.7380	....	....	594	—0.50
7	4	4,426.5	340.5	340.5	340.5	7,264	38.136	50.6160	50.6160	....	4,441	464	+0.83
8	16	2,951.0	227 0	227.0	227.0	5,448	25.424	....	....	....	....	465	+1.07
9	16	3,688.8	283.8	283.8	283.8	5,904	31.780	54.6568	54.6568	....	1,793	539	+1.65
10	16	4,426.5	340.5	340.5	340.5	7,264	38.136	....	....	....	4,525	514	+1.11
PERIOD III													
3	10	5,082.5	1,016.5	....	2,033.0	5,448	56.924	....	....	40	24,708	467	—0.53
4	10	5,082.5	1,016.5	....	2,033.0	7,264	56.924	53.7000	53.7000	40	27,833	488	—0.38
7	16	2,837.5	567.5	....	1,135.0	5,904	31.780	50.6160	50.6160	40	579	493	+1.44
8	7	2,270.0	454.0	....	908.0	5,448	25.424	....	....	40	....	493	+1.33
9	13	3,121.3	624.3	....	1,248.5	4,540	34.958	58.8000	58.8000	40	....	575	+1.20
10	16	3,405.0	681.0	....	1,362 0	5,904	38.136	....	....	40	....	546	+1.65

*This extensive loss in weight occurred during the seven days following parturition. Its extent is due largely to the fact that the ration was maintained the same in amount as in the previous period in which the cow was giving no milk.

TABLE IV.—COMPOSITION OF FEEDS (Percent)

	Dry matter	Ether extract	Crude fiber	Nitrogen	Protein	Nitrogen free extract	Ash	Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus	Silicon	Arsenic
Corn (Per. I)	85.830	4.084	1.62	1.3670	8.5440	70.4970	1.0850	0.0140	0.2665	0.0074	0.0986	.1289	0.0466	0.2273	.0185	....
Corn (Per. II)	86.203	3.890	1.74	1.3780	8.6125	70.8589	1.1016	0.0087	0.2651	0.0110	0.0989	.1286	0.0469	0.2284	.0162	....
Corn (Per. III)	85.469	4.150	1.77	1.3770	8.6063	69.8365	1.1062	0.0155	0.2741	0.0095	0.1051	.1265	0.0436	0.2367	.0141	....
Cottonseed meal (Per. I)	92.770	8.490	7.26	6.3890	39.9313	30.4879	6.6008	0.0313	1.4882	0.1868	0.6230	.4436	0.0288	1.3309	.0383	....
Cottonseed meal (Per. II)	94.067	8.626	8.49	6.6310	41.4438	28.9355	6.5717	0.0345	1.4119	0.1804	0.6255	.4414	0.0313	1.3089	.0372	....
Cottonseed meal (Per. III)	93.385	8.302	6.83	6.5990	41.2438	30.2184	6.7908	0.0291	1.4583	0.1942	0.6770	.4727	0.0291	1.3718	.0309	....
Linseed oilmeal (Per. I)	90.705	8.670	6.49	4.8190	30.1188	39.3387	6.0875	0.0237	1.5136	0.3262	0.5363	.3470	0.0483	1.0020	.0739	....
Linseed oilmeal (Per. II)	91.503	9.178	7.09	5.0190	31.3688	37.7770	6.0892	0.1408	1.4657	0.3336	0.5575	.3442	0.0473	1.0020	.0845	....
Wheat bran (Per. I)	91.231	3.838	6.86	2.5055	15.6594	59.3296	5.5440	0.0119	0.8660	0.0897	0.4797	.2022	0.0344	0.9849	.0580	....
Wheat bran (Per. II)	92.822	4.132	6.82	2.5035	15.6469	60.6956	5.5275	0.0167	0.8652	0.0858	0.4768	.2043	0.0363	0.9862	.0225	....
Wheat bran (Per. III)	92.569	4.222	6.98	2.4868	15.5425	60.3370	5.4875	0.0050	0.9034	0.0872	0.4692	.2038	0.0268	0.9772	.0218	....
Alfalfa hay (Per. I)	91.605	3.025	28.61	2.3097	14.4354	38.0847	7.4499	0.0497	1.4000	1.1784	0.2666	.2387	0.1077	0.1995	.3772	....
Alfalfa hay (Per. II)	91.637	3.335	25.28	2.3481	14.6762	41.2841	7.0617	0.0949	1.4098	1.2107	0.2768	.2479	0.1042	0.1978	.3212	....
Alfalfa hay (Per. III, 7, 8, 10)	90.571	3.188	29.21	2.3530	14.7062	36.7929	6.6739	0.0491	1.4313	1.1324	0.2714	.2296	0.0829	0.2125	.2557	....
Alfalfa hay (Per. III, 3, 4)	90.359	3.110	29.14	2.3473	14.6706	36.7806	6.6578	0.0489	1.4279	1.1297	0.2707	.2290	0.0827	0.2120	.2551	....
Alfalfa hay (Per. III, 9)	90.463	2.857	29.18	2.3501	14.6884	37.0717	6.6659	0.0490	1.4296	1.1310	0.2710	.2293	0.0828	0.2123	.2554	....
Precipitated bone	92.928	....	....	0.1023	0.6394	....	....	....	....	25.6300	0.6225	.3360	2.1670	16.6664	....	....
Calcium carbonate (I)	99.043	....	....	....	....	....	....	....	....	39.6271	0.4060	.0128	0.0015	0.0031	....	....
Calcium carbonate (II, III)	99.085	....	....	....	....	....	....	....	....	39.4834	0.3845	.0067	0.0021	0.0052	....	....
Sodium chloride (I)	99.440	....	....	....	....	....	....	39.1227	....	....	....	....	60.3173	....	....	....
Sodium chloride (II)	99.165	....	....	....	....	....	....	39.0145	....	....	....	....	60.1505	....	....	....
Sodium chloride (III)	99.037	....	....	....	....	....	....	38.9641	....	....	....	....	60.0729	....	....	....
Fowler's Solution	....	....	....	....	....	....	....	....	0.5300	....	....	....	....	....	....	.7196

TABLE V.—COMPOSITION OF MILK (Percent)

Cow No.	Dry matter	Ether extract	Nitrogen	Protein	Nitrogen-free extract	Ash	Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus	Arsenic
PERIOD I														
1	11.19	2.89	0.4276	2.7238	4.89	0.6831	0.0363	0.1280	0.0887	0.0142	0.0269	0.0857	0.0772	....
2	11.49	3.10	.4521	2.8799	4.77	.7408	.0354	.1264	.1061	.0128	.0279	.1109	.0859	....
5	11.30	2.90	.4288	2.7315	4.92	.7548	.0457	.1463	.1035	.0133	.0262	.0944	.0917	....
6	11.30	3.22	.4111	2.6187	4.71	.7472	.0330	.1633	.1052	.0121	.0255	.0907	.0885	....
PERIOD II														
3	14.00	3 75	.8968	5.7126	3.68	.8499	.0706	.1521	.1247	.0163	.0575	.1588	.1146	....
7	11.23	3.03	.6375	4.0609	3.30	.8302	.1427	.0755	.0970	.0157	.0419	.2118	.0749	....
9	12.87	2.86	.8262	5.2629	3.85	.9035	.1431	.0751	.1727	.0167	.0532	.2079	.1164	....
10	13.29	3.37	.6394	4.0730	5.08	.7709	.0814	.0919	.1340	.0164	.0360	.1209	.1082	....
PERIOD III														
3	10.20	2.47	.3934	2.5059	4.53	.6991	.0408	.1647	.0924	.0115	.0232	.1255	.0794	....
4	11.47	3.00	.4471	2.8480	4.92	.7055	.0366	.1509	.1057	.0139	.0273	.0884	.0910	....
7	12.34	1.50	1.1464	7.3026	2.66	.8809	.0239	.0352	.0643	.0196	.0753	.2870	.0704	0.000006

TABLE VI.—CONSTITUENTS OF DAILY RATIONS (Grams)

Cow No.	Dry matter	Ether extract	Crude fiber	Nitrogen	Protein	Nitrogen-free extract	Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus	Silicon	Arsenic
PERIOD I															
1	12,741.912	527.667	2,374.122	303.358	1,896.185	7,091.278	22.216	137.189	129.623	32.742	29.213	39.166	49.468	30.750	....
2	12,236.926	506.552	2,362.246	294.329	1,839.737	6,793.240	20.903	135.100	93.548	31.345	28.261	35.855	38.516	30.633	....
3	8,287.220	332.814	1,653.171	197.294	1,233 197	4,445.934	13.210	92.900	105.962	21.782	19.271	24.150	35.357	21.481	....
4	8,169.027	332.814	1,653.171	197.231	1,232.803	4,445.892	13.210	92.900	65.784	21.148	19.056	22.815	25.094	21.481	....
5	12,327.361	506.552	2,362.246	294.377	1,840.038	6,793.271	20.903	135.100	124.290	31.829	28.419	36.876	46.369	30.633	....
6	13,050.429	541.340	2,503.439	313.742	1,961.082	7,263.384	22.440	143.517	99.073	33.382	30.101	38.461	41.206	32.455	....
PERIOD II															
3	8,193.396	346.282	1,479.450	200.718	1,254.518	4,629.420	15.7821	93.125	67.645	21.766	19.548	22.614	25.001	18.304	....
4	8,313.861	346.282	1,479.450	200.782	1,254.917	4,629.465	15.7821	93.125	108.496	22.398	19.763	23.975	35.460	18.304	....
7	11,555.219	489.141	1,989.632	279.808	1,748.840	6,569.305	22.8107	126.887	123.432	30.646	27.244	34.073	44.143	24.540	....
8	8,193.396	346.282	1,479.450	200.718	1,254.518	4,629.420	15.7821	93.125	67.645	21.766	19.548	22.614	25.001	18.304	....
9	9,516.644	402.650	1,620.288	229.687	1,435.579	5,412.878	18.8655	103.636	109.177	25.252	22.376	28.509	38.573	19.971	....
10	11,458.030	489.141	1 989.632	279.756	1,748.516	6,569.271	22.8107	126.887	90.474	30.136	27.071	32.975	35 705	24 540	....
PERIOD III															
3	12,154.282	550.580	1,888.838	315.502	1,971.892	7,087.068	26.029	125.125	65.776	36.510	27.854	41.758	57.391	25.372	0.28784
4	13,898.313	607.057	2,418.020	358.184	2,238.653	7,755.041	26.917	151.056	121.257	41.967	31.196	44.425	70.188	20.004	.28784
7	9,481.776	401.009	1,892.766	243.720	1,523.248	5,010.212	15.943	111.023	102.176	28.683	22.314	26.790	46.487	15.919	.28784
8	8,164.128	343.914	1,725.926	211.989	1,324.930	4,274.817	13.111	99.235	63.582	24.506	19.377	21.154	32.051	14.589	.28784
9	8,661.016	363.783	1,509.804	221.980	1,387.471	4,804.863	16.574	94.054	92.232	26.261	20.056	27.912	47.594	12.500	.28784
10	10 192.042	443.567	1,926.407	264.617	1,653.858	5,577.763	18.552	116.284	69.691	30.603	23.858	29.852	43.257	16.084	.28784

TABLE VII.—CONSTITUENTS OF AVERAGE DAILY MILK (Grams)

Cow No.	Nitrogen	Ether extract	Ash	Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus	Arsenic
PERIOD I											
1	82.9550	561.4209	132.5224	7.0423	24.8322	17.2079	2.7548	5.2186	16.6259	14.9769	....
2	77.6701	533.1079	127.2683	6.0817	21.7153	18.2278	2.1990	4.7932	19.0525	14.7575	....
5	79.0255	533.7722	139.1055	8.4223	26.9623	19.0745	2.4511	4.8285	17.3974	16.8998	....
6	92.5176	725.1304	168.1566	7.4266	36.7505	23.6752	2.7231	5.7388	20.4119	19.9168	....
PERIOD II											
3	193.1451	808.6766	183.0442	15.2052	32.7580	26.8568	3.5106	12.3839	34.2010	24.6816	....
7	28.3114	134.7355	36.8692	6.3373	3.3530	4.3078	0.6972	1.8608	9.4061	3.3263	....
9	14.8143	51.2332	16.2003	2.5658	1.3466	3.0966	0.2994	0.9539	3.7278	2.0871	....
10	28.9313	152.2986	34.8813	3.6831	4.1582	6.0632	0.7421	1.6289	5.4704	4.8958	....
PERIOD III											
3	97.2013	609.5711	172.7336	10.0809	40.6941	22.8312	2.8414	5.7323	31.0085	19.6182	....
4	124.4413	833.7097	196.3618	10.1869	42 0000	29.4195	3.8688	7.5984	24.6044	25.3280	....
7	6.6377	8.6694	5.1004	1.3827	0.2038	0.3723	0.1135	0.4360	1.6617	0.4076	0.00004

TABLE VIII.—CONSTITUENTS OF AVERAGE DAILY URINE (Grams)

Cow No.	Nitrogen	Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus	Arsenic
PERIOD I									
1	113.3821	9.068	97.832	0.7275	2.8079	10.7360	5.7616	0.1450	....
2	115.0551	12.009	112.285	1.5229	3.9313	11.2618	7.9991	.2429	....
3	105.1468	10.507	90.008	.1301	2.5268	9.1544	16.2200	.1750	....
4	104 7988	9.464	87.595	.1272	2.6443	8.8145	14.3613	.1343	....
5	111.9032	7.900	101.858	.4117	5.3242	11.4433	8.0501	.1265	....
6	109.5575	10.915	97.421	.1178	4.4641	10.4591	3.3379	.1480	....
PERIOD II									
3	115.8428	8.539	65.129	.0902	2.1377	8.9551	1.3020	.1409	....
4	77.6705	8.058	77.235	.3101	1.9002	7.6663	12.3777	.1631	....
7	99.1319	4.896	116.504	.2704	5.0532	9.7782	14.1118	.1681	....
8	88.7819	8.606	83.535	.3715	4.8201	8.3094	9.8151	.1796	....
9	101.9071	6.370	86.150	.4020	2.6884	9.3029	7.2435	.1290	......
10	111.6512	11.342	97.214	.5019	5.9847	10.7738	15.2002	.1606	.. ..
PERIOD III									
3	109.7207	3.9447	63.3444	.0736	5.8416	9.8733	2.5761	4.0945	0.08690
4	103.5912	11.5283	100.8479	.0846	2.9174	10.7390	7.7106	2.2643	.09580
7	114.8959	5.0370	88.9232	.1647	5.8689	9.9785	11.0253	.8606	.08284
8	104.5864	2.0357	84.1701	.8105	4.3515	9.1803	9.7155	.2020	.08979
9	124.7039	8.3898	86.9595	.1434	4.3712	10.2887	15.5105	.1259	.07363
10	147.7644	10.5012	106.6423	.2732	5.0494	12.9980	21.5282	.2027	.05566

TABLE IX.—CONSTITUENTS OF AVERAGE DAILY FECES (Grams)

Cow No.	Total weight	Dry matter	Ether extract	Crude fiber	Nitrogen	Protein	Nitrogen-free extract	Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus	Arsenic
PERIOD I															
1	30,549	4,044.65	194.1064	1,428.8238	106.8288	667.6724	1,329.2350	8.584	14.877	116.7877	33.2370	13.9302	14.6023	32.4733	....
2	23,209	4,247.32	216.5664	1,486.7910	107.2272	670.1700	1,527.1752	4.665	9.260	83.9482	30.6131	13.7167	8.3786	23.8128	....
3	14,140	2,630.00	136.1658	890.3801	59.0052	368 7788	907.7720	3.281	4.680	98.8793	21.4924	8.6678	6.9143	28.7744	....
4	13,355	2,586.79	120.2577	948.4401	61.7648	386.0266	892.0839	3.325	4.554	59.1206	21.4875	8.4668	4.7542	18.9368	....
5	25,780	4,379.99	205.1553	1,464.0320	108.8421	680.2503	1,533.8951	5.723	11.936	143.0003	33.8488	14.4109	11.3947	39.9071	....
6	24,694	4,343.59	174.4345	1,398.6370	112.0342	700.2075	1,731.0108	5.260	10.890	83.0935	31.6076	13.8530	11.6800	23.0637	....
PERIOD II															
3	13,205	2,405.62	104.188	854.522	58.247	364.049	879.090	2.588	8.346	50.179	18.381	7.632	5.163	15.516	....
4	15,586	2,855.32	116.879	1,016.644	63.404	396.274	1,020.306	3.554	5.954	94.186	20.215	8.074	5.284	27.057	....
7	26,120	4,361.10	169.780	1,452.063	109.887	686.799	1,643.941	1.411	15.306	120.596	26.224	12.720	6.843	38.423	....
8	17,551	2,580.07	132.159	1,152.293	62.903	393.142	671.922	4.423	14.497	58.989	17.042	8.091	8.021	19.376	....
9	19,914	3,012.61	133.384	897.345	75.554	472.221	1,164.411	4.242	14.517	97.499	23.180	9.459	13.163	31.245	....
10	21,825	3,596.93	152.164	1,358.061	87.038	543.988	1,242.410	3.099	10.236	75.449	25.513	11.174	8.752	25.186	....
PERIOD III															
3	20,220	3,896.94	167.300	1,241.629	106.377	664.854	1,477.213	11.566	23.759	58.537	31.483	12.274	6.046	44.626	0.15367
4	29,287	4,930.47	180.115	1,557.600	124.235	776.486	2,006.804	6.795	12.535	104.145	26.316	14.409	13.531	49.085	.14058
7	22,272	3,265.81	133.766	1,227.878	76.504	478.158	1,060.815	8.909	18.931	94.166	21.916	10.245	14.900	40.045	.13720
8	19,659	3,850.31	159.415	1,313.772	101.303	633.138	1,414.603	10.321	22.293	57.090	23.198	11.933	5.269	43.741	.10223
9	15,983	2,723.54	106.591	982.347	65.722	410.763	898.133	4.747	8.519	86.995	21.401	8.535	8.039	45.599	.10597
10	18,966	3 283.13	134.791	1,090.431	79.164	494.785	1,253.103	5.709	13.826	65.641	26.344	10.242	7.188	40.891	.10773

TABLE X.—PERIOD I: AVERAGE DAILY BALANCES OF MINERALS (Grams)

Cow No.	Average daily milk yield Grams / Pounds	Distinguishing features of rations	Period of lactation and gestation	Food / Milk / Urine / Feces / Balance	Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus	Nitrogen
1	19,400 42.77	Calcium supplement	Lactation: 139–158 day Gestation: 49–68 day	Food	22.2	137.2	129.6	32.7	29.2	39.2	49.5	303.4
				Milk	7.0	24.8	17.2	2.8	5.2	16.6	15.0	83.0
				Urine	9.1	97.8	0.7	2.8	10.7	5.8	0.1	113.4
				Feces	8.6	14.9	116.8	33.2	13.9	14.6	32.5	106.8
				Balance	−2.5	−0.3	−5.1	−6.1	−0.6	+2.2	+1.9	+0.2
2	17,180 37.87	No calcium supplement	Lactation: 142–161 day Gestation: not bred	Food	20.9	135.1	93.5	31.3	28.3	35.9	38.5	294.3
				Milk	6.1	21.7	18.2	2.2	4.8	19.1	14.8	77.7
				Urine	12.0	112.3	1.5	3.9	11.3	8.0	0.4	115.1
				Feces	4.7	9.3	83.9	30.6	13.7	8.4	23.8	107.2
				Balance	−1.9	−8.2	−10.1	−5.4	−1.5	+0.4	−0.5	−5.7
3	Dry	Calcium supplement	Lactation: Dry Gestation: 246–265 day	Food	13.2	92.9	106.0	21.8	19.3	24.2	35.4	197.3
				Milk	....	....	....	....	....	....	....	....
				Urine	10.5	90.0	0.1	2.5	9.2	16.2	0.2	105.1
				Feces	3.3	4.7	98.9	21.5	8.7	6.9	28.8	59.0
				Balance	−0.6	−1.8	+7.0	−2.2	+1.4	+1.0	+6.4	+33.2
4	Dry	No calcium supplement	Lactation: Dry Gestation: 240–259 day	Food	13.2	92.9	65.8	21.1	19.1	22.8	25.1	197.2
				Milk	....	....	....	....	....	....	....	....
				Urine	9.5	87.6	0.1	2.6	8.8	14.4	0.1	104.8
				Feces	3.3	4.6	59.1	21.5	8.5	4.8	18.9	61.8
				Balance	+0.4	+0.7	+6.6	−3.0	+1.8	+3.6	+6.1	+30.6
5	18,430 40.63	Calcium supplement	Lactation: 55–74 day Gestation: Not bred	Food	20.9	135.1	124.3	31.8	28.4	36.9	46.4	294.4
				Milk	8.4	27.0	19.1	2.5	4.8	17.4	16.9	79.0
				Urine	7.9	101.9	0.4	5.3	11.4	8.1	0.1	111.9
				Feces	5.7	11.9	143.0	33.8	14.4	11.4	39.9	108.8
				Balance	−1.1	−5.7	−38.2	−9.8	−2.2	+0.0	−10.5	−5.3
6	22,505 49.61	No calcium supplement	Lactation: 50–69 day Gestation: Not bred	Food	22.4	143.5	99.1	33.4	30.1	38.5	41.2	313.7
				Milk	7.4	36.8	23.7	2.7	5.7	20.4	19.9	92.5
				Urine	10.9	97.4	0.1	4.5	10.5	3.3	0.1	109.6
				Feces	5.3	10.9	83.1	31.6	13.9	11.7	23.1	112.0
				Balance	−1.2	−1.6	−7.8	−5.4	+0.0	+3.1	−1.9	−0.4

TABLE XI.—PERIOD II: AVERAGE DAILY BALANCES OF MINERALS AND NITROGEN (Grams)

Cow No.	Average daily milk yield Grams Pounds	Distinguishing features of rations	Period of lactation and gestation	Sodium Food Milk Urine Feces Balance	Potassium Food Milk Urine Feces Balance	Calcium Food Milk Urine Feces Balance	Magnesium Food Milk Urine Feces Balance	Sulphur Food Milk Urine Feces Balance	Chlorine Food Milk Urine Feces Balance	Phosphorus Food Milk Urine Feces Balance	Nitrogen Food Milk Urine Feces Balance
3	21,537 47.48	No calcium supplement	Lactation: 1–7 day Gestation: not bred	15.8 15.2 8.5 2.6 —10.5	93.1 32.8 65.1 8.3 —13.1	67.6 26.9 0.1 50.2 —9.6	21.8 3.5 2.1 18.4 —2.2	19.5 12.4 9.0 7.6 —9.5	22.6 34.2 1.3 5.2 —18.1	25.0 24.7 0.1 15.5 —15.3	200.7 193.1 115.8 58.2 166.4
4	Dry	Calcium supplement	Lactation: Dry Gestation: 275–279 day	15.8 .... 8.1 3.6 +4.1	93.1 .... 77.2 6.0 +9.9	108.5 .... 0.3 94.2 +14.0	22.4 .... 1.9 20.2 +0.3	19.8 .... 7.7 8.1 +4.0	24.0 .... 12.4 5.3 +6.3	35.5 .... 0.2 27.1 +8.2	200.8 .... 77.7 63.4 +59.7
7	4,441 9.79	Calcium supplement	Lactation: Nearly dry Gestation: 226–229 day	22.8 6.3 4.9 1.4 +10.2	126.9 3.4 116.5 15.3 —8.3	123.4 4.3 0.3 120.6 —1.8	30.6 0.7 5.1 26.2 —1.4	27.2 1.9 9.8 12.7 +2.8	34.1 9.4 14.1 6.8 +3.8	44.1 3.3 0.2 38.4 +2.2	279.8 28.3 99.1 109.9 +42.5
8	Dry	No calcium supplement	Lactation: Dry Gestation: 248–263 day	15.8 .... 8.6 4.4 +2.8	93.1 .... 83.5 14.5 —4.9	67.6 .... 0.4 59.0 +8.2	21.8 .... 4.8 17.0 —0.0	19.5 .... 8.3 8.1 +3.1	22.6 .... 9.8 8.0 +4.8	25.0 .... 0.2 19.4 +5.4	200.7 .... 88.8 62.9 +49.0
9	1,793 3.95	Calcium supplement	Lactation: Nearly dry Gestation: 182–197 day	18.9 2.6 6.4 4.2 +5.7	103.6 1.3 86.2 14.5 +1.6	109.2 3.1 0.4 97.5 +8.2	25.3 0.3 2.7 23.2 —0.9	22.4 1.0 9.3 9.5 +2.6	28.5 3.7 7.2 13.2 +4.4	38.6 2.1 0.1 31.2 +5.2	229.7 14.8 101.9 75.6 +37.4
10	4,525 9.98	No calcium supplement	Lactation: Nearly dry Gestation: 178–193 day	22.8 3.7 11.3 3.1 +4.7	126.9 4.2 97.2 10.2 +15.3	90.5 6.1 0.5 75.4 +8.5	30.1 0.7 6.0 25.5 —2.1	27.1 1.6 10.8 11.2 +3.5	33.0 5.5 15.2 8.8 +3.5	35.7 4.9 0.2 25.2 +5.4	279.8 28.9 111.7 87.0 +52.1

TABLE XII.—PERIOD III: AVERAGE DAILY BALANCES OF MINERALS AND NITROGEN (Grams)

Cow No.	Average daily milk yield Grams Pounds	Distinguishing features of rations	Period of lactation and gestation	Sodium Food Milk Urine Feces Balance	Potassium Food Milk Urine Feces Balance	Calcium Food Milk Urine Feces Balance	Magnesium Food Milk Urine Feces Balance	Sulphur Food Milk Urine Feces Balance	Chlorine Food Milk Urine Feces Balance	Phosphorus Food Milk Urine Feces Balance	Arsenic Food Milk Urine Feces Balance	Nitrogen Food Milk Urine Feces Balance
3	24,708 54.47	Arsenic, no calcium supplement	Lactation: 30-39 day Gestation: not bred	26.0 10.1 3.9 11.6 +0.4	125.1 40.7 63.3 23.8 —2.7	65.8 22.8 0.1 58.5 —15.6	36.5 2.8 5.8 31.5 —3.6	27.9 5.7 9.9 12.3 —0.0	41.8 31.0 2.6 6.0 +2.2	57.4 19.6 4.1 44.6 —10.9	0.288 .... 0.087 0.154 +0.047	315.5 97.2 109.7 106.4 +2.2
4	27,833 61.36	Arsenic, calcium supplement	Lactation: 24-33 day Gestation: not bred	26.9 10.2 11.5 6.8 —1.6	151.1 42.0 100.8 12.5 —4.2	121.3 29.4 0.1 104.1 —12.3	42.0 3.9 2.9 36.3 —1.1	31.2 7.6 10.7 14.4 —1.5	44.4 24.6 7.7 13.5 —1.4	70.2 25.3 2.3 49.1 —6.5	0.288 .... 0.096 0.141 +0.051	358.2 124.4 103.6 124.2 +6.0
7	579 1.28	Arsenic, calcium supplement	Lactation: nearly dry Gestation: 250-265 day	15.9 1.4 5.0 8.9 +0.6	111.0 0.2 88.9 18.9 +3.0	102.2 0.4 0.2 94.2 +7.4	28.7 0.1 5.9 21.9 +0.8	22.3 0.4 10.0 10.2 +1.7	26.8 1.7 11.0 14.9 —0.8	46.5 0.4 0.9 40.0 +5.2	0.288 0.000 0.083 0.137 +0.068	243.7 6.6 114.9 76.5 +45.7
8	Dry	Arsenic, no calcium supplement	Lactation: dry Gestation: 273-279 day	13.1 .... 2.0 10.3 +0.8	99.2 .... 84.2 22.3 —7.3	63.6 .... 0.8 57.1 +5.7	24.5 .... 4.4 23.2 —3.1	19.4 .... 9.2 11.9 —1.7	21.2 .... 9.7 5.3 +6.2	32.1 .... 0.2 43.7 —11.8	0.288 .... 0.090 0.102 +0.096	212.0 .... 104.6 101.3 +6.1
9	Dry	Arsenic, calcium supplement	Lactation: dry Gestation: 209-221 day	16.6 .... 8.4 4.7 +3.5	94.1 .... 87.0 8.5 —1.4	92.2 .... 0.1 87.0 +5.1	26.3 .... 4.4 21.4 +0.5	20.1 .... 10.3 8.5 +1.3	27.9 .... 15.5 8.0 +4.4	47.6 .... 0.1 45.6 +1.9	0.288 .... 0.074 0.106 +0.108	222.0 .... 124.7 65.7 +31.6
10	Dry	Arsenic, no calcium supplement	Lactation: dry Gestation: 202-217 day	18.6 .... 10.5 5.7 +2.4	116.3 .... 106.6 13.8 —4.1	69.7 .... 0.3 65.6 +3.8	30.6 .... 5.0 26.3 —0.7	23.9 .... 13.0 10.2 +0.7	29.9 .... 21.5 7.2 +1.2	43.3 .... 0.2 40.9 +2.2	0.288 .... 0.056 0.108 +0.124	264.6 .... 147.8 79.2 +37.6

TABLE XIII.—UTILIZATION AND ELIMINATION OF NITROGEN

Cow No.	Average daily milk yield	Distinguishing features of rations	Period of gestation	Nitrogen in rations per day	Nitrogen in urine per day	Nitrogen of food in urine	Utilization* of nitrogen	Nitrogen of food in feces
Period I	*Pounds*		*Days*	*Grams*	*Grams*	*Percent*	*Percent*	*Percent*
1	42.77	Calcium supplement	49-68	303.358	113.382	37.38	27.41	35.21
2	37.87	No calcium supplement	Not bred	294.329	115.055	39.09	24.48	36.43
3	Dry	Calcium supplement	246-265	197.294	105.147	53.29	16.80	29.91
4	Dry	No calcium supplement	240-259	197.231	104.799	53.14	15.55	31.32
5	40.63	Calcium supplement	Not bred	294.377	111.903	38.01	25.01	36.97
6	49.61	No calcium supplement	Not bred	313.742	109.558	34.92	29.37	35.71
Period II								
3	47.48	No calcium supplement	Not bred	200.718	115.843	57.71	13.27	29.02
4	Dry	Calcium supplement	275-279	200.782	77.671	38.68	29 74	31.58
7	9.79	Calcium supplement	226-229	279.803	99.132	35.43	25.30	39.27
8	Dry	No calcium supplement	248-263	200.718	88.782	44.23	24.41	31.34
9	3.95	Calcium supplement	182-197	229.687	101.907	44.37	22.74	32.89
10	9.98	No calcium supplement	178-193	279.756	111.651	39.91	28.98	31.11
Period III								
3	54.47	Arsenic; no calcium supplement	Not bred	315.502	109.721	34.78	31.51	33.72
4	61.36	Arsenic; calcium supplement	Not bred	358.184	103.591	28.92	36.40	34.68
7	1.28	Arsenic; calcium supplement	250-265	243.720	114.896	47.14	21.47	31.39
8	Dry	Arsenic; no calcium supplement	273-279	211.989	104.586	49.34	2.88	47.79
9	Dry	Arsenic; calcium supplement	209-221	221.980	124.704	56.18	14.22	29.61
10	Dry	Arsenic; no calcium supplement	202-217	264.617	147.764	55.84	14.24	29.92

*Utilization, in the sense here signified, is the amount in the milk plus the positive or minus the negative balance, that is, use for constructive purposes other than maintenance.

TABLE XIV.—COEFFICIENTS OF DIGESTIBILITY OF RATIONS

Cow No.	Distinguishing features of rations	Yield of milk Pounds	Protein	Nitrogen-free extract	Ether extract	Crude fiber	Nutritive ratio of rations*
PERIOD I							
1	Calcium supplement	42.77	64.79	81.26	63.21	39.82	1:6.07
2	No calcium supplement	37.87	63.57	77.52	57.25	37.06	1:5.81
3	Calcium supplement	Dry	70.10	79.58	59.09	46.14	1:5.49
4	No calcium supplement	Dry	68.69	79.94	63.87	42.63	1:5.59
5	Calcium supplement	40.63	63.03	77.42	59.50	38.02	1:5.89
6	No calcium supplement	49.61	64.29	76.17	67.78	44.13	1:5.92
PERIOD II							
3	No calcium supplement	47.48	70.98	81.01	69.91	42.24	1:5.53
4	Calcium supplement	Dry	68.42	77.96	66.25	31.28	1:5.34
7	Calcium supplement	9.79	60.73	74.97	65.29	27.02	1:5.82
8	No calcium supplement	Dry	68.66	85.49	61.83	22 11	1:5.53
9	Calcium supplement	3.95	67.11	85.31	66.87	44.62	1:5.79
10	No calcium supplement	9.98	68.89	81.09	68.89	31.74	1:5.58
PERIOD III							
3	Arsenic; no calcium supplement	54.47	66.28	79.16	69.61	34.26	1:5.45
4	Arsenic; calcium supplement	61.36	65.32	74.12	70.33	35.58	1:5.18
7	Arsenic; calcium supplement	1.28	68.61	78.83	66.64	35.13	1:4.99
8	Arsenic; no calcium supplement	Dry	52.21	66.91	53.65	23.88	1:5.33
9	Arsenic; calcium supplement	Dry	70.39	81.31	70.70	34.94	1:5.13
10	Arsenic; no calcium supplement	Dry	70.08	77.53	69.61	43.40	1:5.05

*Nutritive ratios of the rations as digested by the several individuals; no correction was made for metabolic nitrogen.

TABLE XV.—PERIOD I: DISTRIBUTION OF OUTGO OF ELEMENTS AMONG MILK, URINE, AND FECES (Percent)

Cow No.	Distinguishing features of rations, and status of cow, as to lactation		Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus	Nitrogen
1	Calcium supplement; 139–158 day	Milk	28.5	18.1	12.8	7.1	17.5	44.9	31.5	27.4
		Urine	36.7	71.1	0.5	7.2	35.9	15.6	0.3	37.4
		Feces	34.7	10.8	86.7	85.7	46.6	39.5	68.2	35.2
2	No calcium supplement; 142–161 day	Milk	26.7	15.2	17.6	6.0	16.1	53.8	37.8	25.9
		Urine	52.7	78.4	1.5	10.7	37.8	22.6	1.1	38.4
		Feces	20.5	6.5	80.9	83.3	46.1	23.6	61.1	35.7
3	Calcium supplement; dry	Milk	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Urine	76.2	95.1	0.1	10 5	51.4	70.1	0.6	64.1
		Feces	23.8	4.9	99.9	89.5	48.6	29.9	99.4	35.9
4	No calcium supplement; dry	Milk	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Urine	74.0	95.1	0.2	11.0	51.0	75.1	0.7	62.9
		Feces	26.0	4.9	99.8	89.0	49.0	24.9	99.3	37.1
5	Calcium supplement; 55–74 day	Milk	38.2	19.2	11.7	5.9	15.7	47.2	29.7	26.4
		Urine	35.8	72.4	0.3	12.8	37.3	21.9	0.2	37.3
		Feces	26.0	8.5	88.0	81.3	47.0	30.9	70.1	36.3
6	No calcium supplement; 50–69 day	Milk	31.5	25.3	22.1	7.0	19.1	57.6	46.2	29.5
		Urine	46.2	67.2	0.1	11.5	34.8	9.4	0.3	34.9
		Feces	22.3	7.5	77.7	81.5	46.1	33.0	53.5	35.7

TABLE XVI.—PERIOD II: DISTRIBUTION OF OUTGO OF ELEMENTS AMONG MILK, URINE, AND FECES (Percent)

Cow No.	Distinguishing features of rations		Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus	Nitrogen
3	No calcium supplement; 1–7 day	Milk	57.7	30.8	34.8	14.6	42.7	84.1	61.2	52.5
		Urine	32.4	61.3	0.1	8.9	30.9	3.2	0.3	31.5
		Feces	9.8	7.9	65.1	76.5	26.3	12.7	38.5	15.9
4	Calcium supplement; dry	Milk	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Urine	69.4	92.8	0.3	8.6	48.7	70.1	0.6	55.1
		Feces	30.6	7.2	99.7	91.4	51.3	29.9	99.4	44.9
7	Calcium supplement; nearly dry	Milk	50.1	2.5	3.4	2.2	7.6	31.0	7.9	11.9
		Urine	38.7	86.2	0.2	15.8	40.1	46.5	0.4	41.8
		Feces	11.2	11.3	96.3	82.0	52.2	22.5	91.7	46.3
8	No calcium supplement; dry	Milk	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Urine	66.1	85.2	0.6	22.0	50.7	55.0	1.0	58.5
		Feces	33.9	14.8	99.4	78.0	49.3	45.0	99.0	41.5
9	Calcium supplement; nearly dry	Milk	19.5	1.3	3.1	1.1	4.8	15.4	6.2	7.7
		Urine	48.3	84.4	0.4	10.3	47.2	30.0	0.4	53.0
		Feces	32.2	14.2	96.5	88.6	48.0	54.5	93.4	39.3
10	No calcium supplement; nearly dry	Milk	20.3	3.7	7.4	2.3	6.9	18.6	16.2	12.7
		Urine	62.5	87.2	0.6	18.6	45.7	51.7	0.5	49.1
		Feces	17.1	9.2	92.0	79.1	47.4	29.7	83.3	38.2

TABLE XVII.—PERIOD III: DISTRIBUTION OF OUTGO OF ELEMENTS AMONG MILK, URINE, AND FECES (Percent)

Cow No.	Distinguishing features of rations		Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus	Arsenic	Nitrogen
3	Arsenic; no calcium supplement: 30–39 day	Milk	39.4	31.8	28.0	7.1	20.6	78.2	28.7	0.0	31.0
		Urine	15.4	49.6	0.1	14.5	35.4	6.5	6.0	36.1	35.0
		Feces	45.2	18.6	71.9	78.4	44.0	15.3	65.3	63.9	33.9
4	Arsenic; calcium supplement; 24–33 day	Milk	35.7	27.0	22.0	9.0	23.2	53.7	33.0	0.0	35.3
		Urine	40.4	64.9	0.1	6.8	32.8	16.8	3.0	40.5	29.4
		Feces	23.8	8.1	77.9	84.3	44.0	29.5	64.0	59.5	35.3
7	Arsenic; calcium supplement; nearly dry	Milk	9.0	0.2	0.4	0.4	2.1	6.0	1.0	0.0*	3.3
		Urine	32.9	82.3	0.2	21.0	48.3	40.0	2.1	37.6	58.0
		Feces	58.1	17.5	99.4	78.6	49.6	54.0	96.9	62.3	38.6
8	Arsenic; no calcium supplement; dry	Milk	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Urine	16.5	79.1	1.4	15.8	43.5	64.8	0.5	46.8	50.8
		Feces	83.5	20.9	98.6	84.2	56.5	35.2	99.5	53.2	49.2
9	Arsenic; calcium supplement; dry	Milk	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Urine	63.9	91.1	0.2	17.0	54.7	65.9	0.3	41.0	65.5
		Feces	36.1	8.9	99.8	83.0	45.3	34.1	99.7	59.0	34.5
10	Arsenic; no calcium supplement; dry	Milk	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Urine	64.8	88.5	0.4	16.1	55.9	75.0	0.5	34.1	65.1
		Feces	35.2	11.5	99.6	83.9	44.1	25.0	99.5	65.9	34.9

*Trace.