THE MINERAL METABOLISM OF THE MILCH COW

THIRD PAPER

OHIO
Agricultural Experiment Station

WOOSTER, OHIO, U. S. A., SEPTEMBER, 1918

BULLETIN *330*

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BULLETIN

OF THE

Ohio Agricultural Experiment Station

NUMBER 330 SEPTEMBER, 1918

THE MINERAL METABOLISM OF THE MILCH COW

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PART I—THIRD EXPERIMENT

E. B FORBES, J O. HALVERSON AND L E. MORGAN WITH COLLABORATION BY J A. SCHULZ, C. E. MANGELS, S. N. RHUE AND G. W. BURKE

The cow is foster-mother of the human race. This relation, older than the art of writing, grows in prominence as a factor in nutrition with our advance in the science of living; and on both physiologic and economic grounds we anticipate continued increase in the contribution of the cow to the human diet.

This expectation is based on the facts that among farm quadrupeds the cow is by far the most economical producer of protein nutriment; that among proteins in general those contained in milk possess a maximum nutritive value; that milk possesses other important growth-promoting principles the exact nature of which is as yet unknown, and that no other food carries such an abundance of mineral nutrients of desirable kinds and combinations. No other food has an equal value for the general purpose of health insurance.

Since milk is preeminently a protein food it is natural that the protein requirement of cows should have been worked out with great elaboration, and that successful production should depend on a practical recognition of the cow's imperative need for the protein raw material which she transforms.

The fact that the cow is also unparalleled as a producer of mineral nutriment, and that her mineral food requirements must be of a corresponding order, appears to have been overshadowed by the more prominent facts as to her nitrogen metabolism; and we have not been obliged to study the cow's mineral metabolism since, in the provision of her more obvious requirements, we have incidentally and unintentionally done fairly well in providing the necessary mineral substances. In this day of rigorous searching for the true inwardness of things, however, we should no longer delay a careful examination into the terms on which the cow conducts her extensive mineral exchange.

During the past 3 years the main line of work of this department has been an investigation of this subject. This program has embraced three experiments, with six cows in each. There were three experimental periods in the first test and two in each of the others. Our conclusions rest, therefore, on 42 individual studies.

The results from the first and second of these experiments have been published as Bulletins 295 and 308 of the Ohio Experiment Station. The results of the third experiment are presented in this paper, together with a discussion covering the results of the entire series.

OBJECTS OF THE EXPERIMENT

The general object of this investigation was to study the mineral metabolism of the milch cow under conditions such that the results would bear directly on the practical management of dairy cattle, to elucidate the terms on which the extensive mineral exchange of the cow is conducted, and to determine the conditions under which mineral equilibrium may be maintained during profitable milk production.

The first of these experiments was a study of common, practical winter rations composed of hay, corn silage, corn meal and protein concentrates. The several rations differed as to kind of hay (clover or timothy), or kind of protein concentrate (cottonseed meal, linseed oilmeal, distiller's grains or gluten feed).

The rations in the second experiment were similar to those in the first, but the hay was in each ration either clover or alfalfa; and these mineral-rich rations were further fortified, in certain cases, by the addition of steamed bone flour or of calcium carbonate.

In the third experiment, the detailed results of which are here presented, the mineral nutrients of the basal rations were increased by the dropping out of corn silage, and the use of alfalfa hay as the sole roughage; then, in certain cases, these rations were supplemented by the addition of precipitated bone flour, calcium lactate or calcium chloride; these particular calcium preparations being chosen on account of their ready solubility, the chloride and lactate being water-soluble, and the precipitated bone flour (largely in the dicalcic form) being readily soluble in acid.

The rations of the three experiments, therefore, constitute a progressive series in the amounts and solubility of the mineral nutrients. The mineral contents of the rations of the third experiment may be considered as approximating the maximum practicably attainable.

Briefly stated, the object of the first experiment was to study types of rations used in practice; of the second to determine the effects of steamed-bone flour and calcium carbonate when administered in the ration; and of the third to study the more readily soluble precipitated bone flour, calcium lactate and calcium chloride, also when used as supplementary foods.

METHOD OF EXPERIMENTATION

The method of this study, as also that of the preceding two, involved the complete chemical accounting for food, milk, urine and feces. Details of procedure were the same as published in Bulletin 295. As in the earlier experiments, six Holstein cows were used, in collection periods of 20 days each (except where shorter periods were necessitated by irregular behavior of the subjects). These periods were separated by 10-day intervals on the ration to be used in the collection period to follow. The cows, during the experiment, had not been bred. They were fed and milked four times daily, at 6-hour intervals. As to quality they were good, profitable cows, better than the average, but of a grade readily attainable by selective breeding. They were cows such as a successful commercial dairyman expects to have.

During the preliminary feeding the amounts of the feeds were so adjusted that they would be consumed without waste, and there were no refused feeds to be accounted for. The amounts of the mineral supplements to be administered were determined by trial during the preliminary feeding. Varying individual tolerance for these salts was manifest. It was necessary in four cases out of the twelve to start the collection period late, or to terminate it early, on account of unsatisfactory behavior of some one of the experimental subjects.

RATIONS

The basal ration fed was composed of the same feeds in all cases. These were corn meal, cottonseed meal, linseed oilmeal, wheat bran and alfalfa hay. The nutritive ratios of the digested nutrients during the first period averaged 1:5.72. During the second period the additional amounts of alfalfa hay given served to increase the proportion of protein to non-protein to 1:4.50.

In Period I, Cows 1, 2 and 3 received the basal ration alone, while Cows 4, 5 and 6 received the same ration plus precipitated bone flour.

In Period II, Cows 1, 2 and 3 received the basal ration plus calcium lactate, while Cows 4, 5 and 6 received the same plus calcium chloride.

These rations may be considered, then, as closely approximating maximum nutritive value, and possessing all of the characteristics of high-class milk-producing rations except that they contained no succulent feeds such as silage or roots.

RESULTS OF THE EXPERIMENT

Table I, page 119, sets forth the total amounts of feeds consumed and of milk produced, and the live weights of the cows. In consideration of the natural variability of the live-weight of a cow there were no notable changes in the weight of the experimental subjects, except in the case of Cow 6 in Period II. Here the apparent gain in weight doubtless represented actual increase in body substance. In general, as in the previous experiments, the live-weights were maintained practically constant, and, in the consideration of the experimental data, we may dismiss from our minds the factor of gain or loss in body weight.

The statement of the number of days each cow was fed, in the first column of the table, indicates that in four cases it was necessary to depart from the plan of the experiment, on account of accident or irregularity of behavior of the cows. In the case of these individuals which were not fed for the full 20 days the element of inaccuracy in the results was undoubtedly higher than in other cases, and due weight should be given this fact in the interpretation of the data.

Table II, page 120, records the daily amounts of feeds consumed and of milk produced, in grams. A statement of the same matter, in pounds, may be found in Table XI, page 130. It will be observed that the nitrogenous concentrates were fed at all times in the proportion of 2 parts cottonseed meal, 2 parts linseed oilmeal and 1 part wheat bran.

In Period I we fed 16 pounds each of grain and hay. Of the grain 11 pounds was corn meal, and 5 pounds was nitrogenous concentrate. The daily milk production in the case of the cows which were on feed for the full 20 days was 47.2 pounds. These figures will indicate to the dairyman that the cows were full-fed. For maximum production and profit the rations could have been improved by the introduction of corn silage, and reduction of the amount of grain.

In Period II the basal ration was the same as in Period I, except that on account of the hunger of the cows, due largely to lack of bulk in the ration, the alfalfa hay was increased to 18 pounds per day. The milk production of the cows which were on feed the full 20 days averaged 49.9 pounds each, per day.

The amount of precipitated bone flour fed to Cows 4, 5 and 6 in Period I was arbitrarily fixed. The calcium given in this form amounted to 17.1173 gm. per head per day. No difficulty was experienced in the feeding of this preparation. Animals will eat it in indefinite quantities. The calcium lactate fed to Cows 1, 2 and 3 in Period II was not so well taken. The amounts administered to Cows 2 and 3 required careful adjustment and readjustment. Cow 1 consumed the full amount offered her for the full 20 days. The calcium fed these three cows in this form was 15.3602 gm., 7.9259 gm. and 12.4892 gm., respectively, per day.

Table III, page 121, indicates the composition of the feeds. These were not far from normal, except for the cottonseed meal, which contained 19.04 percent of crude fiber and only 23.51 percent of protein. Obviously this product was grossly adulterated with ground hulls. In case of the calcium lactate several lots were used, and not all of them were subjected to complete analysis, the content of certain constituents which were present in small amounts being assumed (as indicated by parentheses) from the analysis of other lots received from the same manufacturer.

Among the notable details of composition of these feeds are the high potassium content of the alfalfa fed in Period II, the characteristically high calcium content of both samples of alfalfa, the low calcium content of the corn meal, the high phosphorus content of the wheat bran, and the high silicon content of the linseed oilmeal and alfalfa hay.

Table IV, page 122, records the composition of the milk. It is a well-known fact of physiology that the composition of cow's milk cannot be altered in important ways, through the character of the feed, so long as the cow remains in a normal state of health, though the evidence on this subject does not preclude the possibility of any such effect whatever. Such being the situation we draw no conclusions from this work, as demonstrating specific effects of the mineral supplements used, on the composition of cow's milk, but would call attention to the fact that, in comparing the milk of Cows

4, 5 and 6 in Period I with the same in Period II, the three differ together (that is, in the same direction), as to ash, sodium, calcium, potassium, sulphur and phosphorus contents. In all cases these differences are slight, and perhaps within the normal range of variation.

Table V, page 123, records the amounts of the constituents of the average daily rations. The main differences in the totals of the nutriment of a given kind, as fed in the two periods, are due to the increase in the alfalfa hay fed in Period II above the amount fed in the previous period, and also to marked differences in the composition of the hay fed in these two periods. The alfalfa fed in Period I was grown in Ohio, and that fed in Period II was grown in the far west, being purchased in the Chicago market.

The influence of these differences in the amount and source of the hay are reflected in the increased amounts of nitrogen, nitrogen-free extract, calcium, potassium, sulphur, chlorine and silicon, and decreased amounts of sodium and magnesium present in the rations fed in the second period.

Tables VI, VII and VIII, pages 124 to 126, set forth the amounts of the constituents present in the milk, urine and feces, and are included merely for the sake of convenient reference, and for the completion of the records.

The main results of the experiment, the balance data for the mineral elements and nitrogen, are reported in Tables IX and X, pages 127 and 128. Considering the results for Period I, these data afford a basis for judging of the effects of adding precipitated bone flour (Cows 4, 5 and 6) to the basal ration (Cows 1, 2 and 3). Since the facts must be judged by the comparison of results from different cows we can draw conclusions only from extensive and therefore unmistakable differences.

The only significant effects observed, of the feeding of the bone flour, were probable decreases in the losses of calcium and phosphorus from the body. Omitting Cow 2 from this consideration the calcium loss in Cows 1 and 3 averaged 10.320 gm., and in Cows 4, 5 and 6, which received the precipitated bone flour, the loss was 5.999 gm.; and the latter group, with their heavier milk production, also had the greater calcium need. The difference between the calcium intake of the two groups was 17.117 gm. Phosphorus retention was indicated by the fact that whereas the loss of phosphorus from the bodies of Cows 1 and 3 averaged 5.983 gm. the loss from Cows 4, 5 and 6 which received the bone flour, was but 1.868 gm. per head per day.

The balances of income and outgo during this period were almost all negative; that is, there was a loss of minerals. Only in the case of sodium does the intake appear to have fulfilled the requirements. In almost all cases, however, the intake of the several elements greatly exceeded the combined amounts of the same found in the milk and urine; and in the cases of potassium, magnesium and sulphur, in spite of negative balances, there was in each case a greater quantity of these elements in the urine than in the milk; also, large amounts of these elements appeared in the feces. This general situation appears not to have been influenced in any certain way by the relative solubilities of the compounds of the elements in question. The results, therefore, indicate conditions unfavorable for mineral retention rather than deficient intake of the same.

Turning now to Table X, page 128, these data apply to the same six cows referred to in the previous table, and furnish a basis for comparison of the results of adding calcium lactate and calcium chloride to the basal ration. This comparison would be made from results obtained with different cows; but by the comparison of results in Table IX with those in Table X we are also able to study two treatments applied to the same cows in two groups of three individuals each.

First, comparing the balances for Cows 1, 2 and 3 in Periods I and II, the differences in feeding are that in Period II the amount of alfalfa hay was increased, and a different lot of hay, differing much in composition, was used; and calcium lactate was added to the ration. One should also bear in mind the fact that since Cow 2 in Period I and Cows 2 and 3 in Period II were in the test for 8 to 10 days only emphasis on the results should be placed accordingly.

The significant differences in the intake caused by the abovementioned changes of ration were a slight decrease in sodium and magnesium, slight increase in phosphorus, and marked increase in potassium, calcium, sulphur, chlorine and nitrogen.

The decrease in sodium intake seems to have lowered the sodium retention, the reduced intake of magnesium seems also to have produced slightly decreased retention, but the differences are of doubtful significance. The slight increase in phosphorus intake caused a slightly greater retention of this element. The large increases in potassium and nitrogen caused decided improvement in their retention; the large increases in sulphur and chlorine caused but slightly improved retention, while there is no evidence that any part of the extensive increase in calcium was retained, in fact, the negative calcium balances were in every case increased.

Let us now compare the balances for Cows 4, 5 and 6 in the two periods. In this case there is the previously mentioned difference in amount and composition of alfalfa; and further, the mineral supplement was precipitated bone flour in Period I and calcium chloride in Period II. These differences in treatment resulted in slight decreases in the intake of sodium, magnesium and phosphorus, and large increases in the intake of potassium, calcium, sulphur, chlorine and nitrogen in Period II as compared with Period I.

The slight decreases in sodium and magnesium intake usually caused slight decreases in the retention of these elements, but a similar decrease in the intake of phosphorus caused no certain change in phosphorus retention.

The large increases in the intake of potassium, sulphur, chlorine and nitrogen all caused definite improvement in the retention of these elements, but, as before, the greater calcium content of the ration in Period II was accompanied by increased loss of this element.

Now, comparing the balances for Cows 1, 2 and 3 with the same for Cows 4, 5 and 6, in Period II, we observe the effects of the difference between calcium lactate and calcium chloride. As before observed we had difficulty in the feeding of the lactate to Cows 2 and 3; on this account our only entirely satisfactory basis for judgment as to the metabolism of this compound is furnished by Cow 1. This comparison gives us but two points worthy of record; the very great increase of chlorine in the ration, due to the feeding of calcium chloride, caused a slight but definite increase in the chlorine retention, and a larger increase in the retention of sodium. The calcium of these two supplements seems not to have been retained.

The most important fact developed by these data is that, irrespective of conditions, and in spite of large intake of calcium, this element was eliminated in quantities greater than were contained in the feed. There is but slight evidence that the precipitated bone flour was utilized, and no evidence that the calcium lactate or the calcium chloride were utilized; there is no evidence, therefore, that the limited utilization of calcium by milk-producing cows is due to the limited solubility of the calcium compounds of the ration.

It is worthy of note, also, that the cows were markedly irresponsive to the intake of magnesium and phosphorus, with which calcium is combined in the skeleton, and that the balances for these elements remained almost invariably negative in spite of the presence in the rations of amounts of the same very much greater than were utilized.

The fact that the heavily-milking cow loses calcium at the same time that she receives a readily assimilable supply greatly in excess of the amount utilized shows that the calcium stores of the body (the skeletal stores) are more readily accessible for use in milk production than is the calcium of the ration.

The cow can store fat and protein in considerable quantities in spite of heavy milk production, but her capacity to assimilate mineral matter, especially calcium, appears to be of a distinctly lower and more definitely limited order.

Common salt was fed in the amount of 42 grams per day to each cow. This furnished from two-thirds to four-fifths of the total sodium of the rations, and permitted considerable storage of this element. The accompanying chlorine, however, was insufficient to meet the demands of milk production, since the chlorine balances were all negative, except where an extra amount was given in the form of calcium chloride to Cows 4, 5 and 6 in Period II. With these three cows there was chlorine retention, the amounts stored (1.261-2.378 grams) being comparatively small. The chlorine intake which resulted in loss from the body was 31.450 to 53.751 grams; where retention of chlorine occurred the intake was 79.412 grams. The requisite amount is undoubtedly affected in a prominent way by the extent of the milk production.

The potassium intake in Period I (88.671 to 105.788 grams) seemed to be insufficient to maintain potassium equilibrium. In Period II the change in amount and kind of alfalfa increased the intake of potassium to 245.069-294.503 grams, and the balance became positive, the storage being 6.415 to 10.738 grams per day.

From these data it would appear that a ration containing as much as 16 pounds of alfalfa hay might be deficient in potassium, but it may be that both the positive and negative balances of potassium represent unimportant fluctuations in extensive reserves of this element.

Eleven out of the twelve sulphur balances were negative. In considering the significance of sulphur balance data one naturally compares them with the associated nitrogen balances, since these two elements are consumed almost wholly in chemical combination in the protein of the ration.

Both sulphur and nitrogen balances were negative in Period I. In Period II there was marked increase in the intake of both of these elements. Nitrogen balances became positive, and the losses of sulphur were reduced, the balances, however, remaining negative. In these rations, therefore, an amount of protein sufficient to provide for nitrogen storage failed to provide enough sulphur to maintain equilibrium of this element.

Table XI, page 129, is presented merely as a convenient summary of the data contained in the two preceding tables, but with the amounts of feeds consumed and of milk produced expressed in pounds. The average daily intake and balances of the nutrient elements are stated in grams.

Table XII, page 131, presents a computation of the amounts of the mineral elements of the rations expressed in terms of cubic centimeters of normal solutions; also a statement of the total acid and total base, and of the amount of the excess base in the rations. The result of this computation is not considered as applying closely to the physiology of mineral metabolism, but merely affording a basis for a general idea as to the relative amounts of acid and base in the feeds.

Calcium and potassium are shown to be the predominant bases, while phosphorus is the predominating acid element in these rations. Silicon is also shown to be present in considerable quantity, and on this basis of computation, to exceed chlorine. No distinction was made, however, between the silicon present as insoluble silica and that contained in the feeds in the form of readily soluble silicates. The fact that silicon enters into the mineral metabolism of the cow, and so must be considered in connection with this acid-base balance, was observed in the first of this series of investigations (Bul. 295).

Table XIII, page 132, exhibits data on the utilization and elimination of nitrogen. On a number of accounts conditions were not favorable for close comparisons of results with reference to nitrogen metabolism; thus, the nitrogen intake in Period II was much greater than in Period I; the proportion of the total nitrogen of the rations in Period II which was contributed by alfalfa hay was also greater than in Period I; further, this hay was of a different lot, and differed much in composition from the hay fed in Period I. A considerable amount of individuality is manifest in the behavior of the cows, especially those which on account of unsatisfactory behavior were not in the experiment for the full periods. As much as we are able to say in regard to these data is that they do not show any effects of the mineral supplements on the nitrogen metabolism. Since nitrogen and mineral metabolism are to a large extent independent there is no reason to suppose that a particularly different conclusion could have been drawn even if the conditions for this observation had been more favorable.

Table XIV, page 132, records the digestion coefficients of the protein, nitrogen-free extract, ether extract and crude fiber of the rations. No correction was made for metabolic nitrogen, since investigations in this laboratory have shown that we have, in reality, no scientific basis for a method of making such an estimation. The nutritive ratios of these rations were computed from the data for intake and feces for each cow. A considerable degree of variability is observable in these digestion coefficients, but there is neither certainty nor even probability that the digestion coefficients were modified by the mineral supplements fed. The nutritive ratio in Period II was narrower than in Period I, because of the differences, which have been mentioned, in the amount and composition of the alfalfa hay.

Tables XV and XVI, pages 133 and 134, display the percentages of the total outgo of the several elements between milk, urine and feces. It will be observed that the percentages of the total outgo of sodium, potassium and chlorine found in the milk were less in the case of each cow in the second period than in the first.

In the case of sodium the amount as well as the percentage in the milk was lower in the second period, as was also the sodium intake, but such was not the case in regard to potassium and chlorine.

The main chemical fact upon which is based the behavior of these elements in the eliminative process is the ready solubility of their compounds, and one of the chief physiological considerations which contribute to the determination of the path of outgo is the length of time the food or food residues remain in the alimentary tract. In accord with individual conditions in the digestive tract, then, there may be great variability in the relative outgo of these elements in urine and feces, but, except in cases of digestive disorder, the proportion of the outgo occurring in the urine usually greatly exceeds that occurring in the feces.

The significance of the lower percentages of the outgo of these elements in the milk in Period II than in Period I is most readily comprehended by directing the attention to the intake of these elements and to the outgo in urine and feces.

In the case of sodium 29.5 percent of the total in the rations in Period I were contributed by alfalfa; in Period II only 14.7 percent of the sodium was contributed by this feed, the amounts contributed by other feeds remaining the same. The data signify in relation to sodium, then, that with a larger sodium intake, a larger proportion of which was contributed by alfalfa, a larger amount and proportion of the sodium outgo appeared in the milk; and of the remainder a larger proportion occurred in the feces (in five cases out of six). In this connection it seems judicious to remark that the difficulties in the way of accurate sodium estimations are great; and that the path of outgo of sodium is often determined by conditions as to the nature of which we can but speculate.

In the case of potassium and chlorine the smaller proportion of the total outgo occurring in the milk in Period II is not due to smaller amounts in the milk, but to much larger intake, the amounts in the milk remaining about the same. The great increase in the intake of these elements was nearly all absorbed, and excreted in the urine.

No effect of the larger ingestion of chlorine as calcium chloride by Cows 4, 5 and 6 in Period II was observable in the quantitative excretion of the bases. This chlorine was eliminated in the urine, probably in combination with bases ingested as organic acid salts, thus serving to reduce the carbonate content of the urine.

This investigation revealed no unmistakable effects of the mineral supplements administered on the paths of outgo of calcium, magnesium and phosphorus.

Sulphur left the body in the case of each cow in larger proportion in the urine than in the milk. At the same time 11 out of the 12 sulphur balances were negative. In Period I more sulphur was eliminated in the feces than in the urine, but in Period II, with an increased sulphur intake, there was in each case an increased amount and proportion of sulphur in the urine. There was some increase in the retention of sulphur in each case, but five out of the six sulphur balances remained negative. There is no evidence of an effect of the mineral supplements on the path of outgo of the sulphur.

Nitrogen is not closely related to the minerals in their metabolism, and we observed no evidence in the data on outgo of nitrogen to indicate such a connection. The elimination and retention of nitrogen was not shown to be affected by circumstances other than the intake of this element. The intake in Period I was slightly deficient; the liberal increase in Period II is reflected in improved retention, with change of balances from negative to positive, increased proportion of outgoing nitrogen in the urine, and decreased proportion in milk and feces.

SUMMARY OF RESULTS

This experiment consists of a study of the metabolism of certain readily soluble inorganic salts and preparations, namely calcium chloride, calcium lactate and precipitated bone flour during the height of the milk flow.

The feeding of precipitated bone flour to cows, during heavy milk production, and in a period characterized by outgo of calcium and phosphorus in amounts greater than the intake, appears to have resulted in the retention of appreciable amounts of the calcium and phosphorus of this supplement, but the utilization was strikingly inefficient, in fact the mineral metabolism as a whole was characterized by a failure to make economical utilization of these elements of the ration

The calcium of calcium lactate and calcium chloride was not retained, but the chlorine of calcium chloride appears to have been retained in slight proportion, and to have rendered possible an increased retention of sodium from the ration.

In general, the differences in the utilization of the mineral nutrients, caused by changes in the ration, were in harmony with the nature of the change; that is, an increase in the intake of an element was usually followed by an increased storage, or decreased loss, of this nutrient, but the response was usually so slight, in comparison with the extent of the change of intake, that it became apparent that the mineral metabolism of the well-fed, heavily milking cow is not intimately and directly dependent upon the mineral nutrients of the ration, but that its character is determined under normal conditions 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.

The most important result of this experiment was the demonstration of the fact that the limited utilization of the mineral nutrients, especially of compounds of calcium, is not determined primarily by their conditions as to solubility.

Common salt in the amount of forty-two grams per head per day provided for the storage of sodium, but furnished an insufficient supply of chlorine. Chlorine was stored only where an added amount was fed in the form of calcium chloride.

The potassium balances indicate that a ration must contain an abundance of roughage in order to maintain equilibrium of this element. With hay only as a roughage; that is, without silage, it is not always possible to maintain the body stores of potassium, but it is true that under some circumstances it is impossible to determine whether negative potassium balances signify actual deficiency of this element in the ration or only unimportant fluctuations in a body supply normally maintained at a level providing a liberal factor of safety.

In this experiment an intake of protein sufficient to provide for nitrogen storage was insufficient to maintain the sulphur equilibrium. In spite of a general harmony in the metabolism of sulphur and nitrogen, as would be anticipated on account of their combination in the proteins of the foodstuffs, there is a degree of independence in the metabolism of these two elements the signifcance of which is not explained by our data.

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.

Some of the main facts determining the path of outgo of sodium, potassium and chlorine are their ready solubility and the length of time the food residues remain in the alimentary tract. The chlorine of calcium chloride was eliminated in the urine, and the calcium in the feces.

Calcium and phosphorus were eliminated almost wholly in the feces; that is, the urine contained but very little of either; the milk, however, contained an abundance of each (always more calcium than phosphorus), and a larger proportion of the food phosphorus than of the food calcium.

Magnesium was excreted in the urine in much greater quantities than either calcium or phosphorus. In eight cases out of twelve more magnesium was eliminated in the urine than in the milk, but in eleven cases out of twelve the total magnesium outgo exceeded the intake.

Sulphur, likewise, left the body in each case in larger proportion in the urine than in the milk, but in eleven cases out of twelve the sulphur outgo exceeded the intake. The path of outgo of sulphur, as between urine and feces, is much affected by the amount of sulphur intake.

The nitrogen retention is controlled closely by the intake, and is not at all closely related to the mineral metabolism. Increased nitrogen intake, until a limit is reached, causes commensurate increase in retention, and increase in the proportion of the total outgo appearing in the urine.

PART II—SUMMARY OF RESULTS FROM THE THREE YEARS' WORK, WITH A DISCUSSION OF PRACTICAL BEARINGS

These results were obtained with high-grade Holstein cows of good productive capacity, most of them from 4 to 6 years of age, during the first half of the period of lactation, and in the winter and early spring months. They were confined in stalls in a cool room, and were given no unrestricted exercise, but the stalls allowed considerable freedom of movement. They were not bred during these investigations. In most essentials the conditions of feeding and care closely approximated those existing in practice. There were, in general, no significant changes in live-weight.

This series of experiments affords us opportunity for a considerable number of comparisons of feeds and of mineral supplements in their effects upon mineral metabolism; thus clover hay is compared with timothy hay and with alfalfa hay; among protein concentrates cottonseed meal, linseed oilmeal, gluten feed and distiller's grains are compared; and among mineral supplements we have compared steamed bone flour, precipitated bone flour, calcium carbonate, calcium lactate and calcium chloride.

Sodium and Chlorine.—The common salt fed in the several periods was in the amount of 28, 42 or 56 grams per head per day. In thirty-one balances out of forty-two sodium was stored, and likewise chlorine in twenty balances. There is some indication in the data that the requirement for chlorine is decidedly greater than for sodium, but the facts are obscured by the difficulties met with in the estimation of sodium, and by the fact that the outgo of these elements from the body may be prominently affected by such conditions as temperature, water drunk, and rapidity of passage of the food through the alimentary tract.

The cow normally carries a considerable excess of both of these elements in the body, which can be drawn upon in considerable amounts without injury to the animal, in the event of temporary shortage. The natural tendency of the cow is to maintain equilibrium of these elements at a high level of reserve supply. Considerable gain or loss of these elements during 20-day balance periods may represent only fluctuations in the reserve, without significant bearing on actual requirements. Neither can be stored up indefinitely. There is a large measure of independence in the metabolism of chlorine and the bases with which it is united in the food; thus, the chlorine of calcium chloride may all be eliminated in the urine, while at the same time its calcium is all eliminated in the intestine; and considerable independence in the elimination of sodium and chlorine is also manifest at times. The normal reserves of these elements are so extensive that the accurate determination of the real nutritive requirements would call for an extended investigation, in point of time.

For practical purposes it is sufficient to feed a cow from 1 to 2 ounces of common salt per day, according to whether she is a moderate or heavy milker, and then, as a safety provision, to allow free access to rock salt in addition.

Comparing the chlorine of the intake, urine and feces of one period with another, when the intake was low the urinary chlorine was lower than the feces chlorine. The chlorine of the urine exceeded that of the feces only when the intake was high. With very low intake the chlorine disappeared from the urine, but considerable amounts remained in the feces; or, stating the matter in another way, when the intake was very low the apparent absorption remained incomplete, and all or nearly all of that which was absorbed went into the milk.

The conditions governing the elimination of sodium are complex, and are not readily analyzed. Urinary sodium exceeded the fecal sodium in twenty-two out of forty-two cases. The distribution was not determined directly by the intake; it appeared to be an individual peculiarity of the animal, the length of time the food residues remained in the digestive tract being one factor of importance. In some cases nearly all of the sodium was excreted in the urine, while in others it was almost all in the feces.

Potassium.—The potassium intake was probably more than sufficient in all cases, since the amount of this element eliminated in the urine always greatly exceeded the amount in the milk; at the same time there were nine negative balances out of the forty-two, the significance of which is not explained with certainty. Apparently these negative balances signify only unimportant fluctuations in extensive reserves.

Potassium was eliminated in the urine in amounts very much greater than in the feces in all cases except where timothy hay was fed. (See Bul. 295, page 342.) This timothy hay, largely through its high silicon content, rendered the urine acid, under which circumstances the potassium was eliminated in the feces much more largely than in the urine.

Nitrogen and Sulphur.—Nitrogen was retained in twenty-nine out of the forty-two cases. Of the thirteen negative balances seven occurred during the feeding of the basal or unsupplemented rations. Nitrogen storage prevailed in 86 percent of the cases where mineral supplements were used. There is no evidence, therefore, that prevailing negative balances were in any way due to the state of the nitrogen metabolism; in fact, throughout this investigation there is no evidence of any direct relation between the nitrogen and the mineral metabolism, except that there is a general parallelism in the metabolism of nitrogen and sulphur, by virtue of their combination in the proteins, but even here the agreement is by no means complete, since in nine cases out of forty-two the signs of the balances differed; that is, one of these elements was stored while the other was given off in amounts greater than the intake. These differences may depend upon the considerable variation which exists in the relative amounts of nitrogen and sulphur in the nitrogenous structures of the body, referring especially to keratin and muscular tissue.

That there is a relation between the metabolism of nitrogen and each of the mineral nutrients is undoubtedly a fact, but the connection is not readily demonstrable, and ordinarily becomes manifest only as the general health of the animal is affected through long-continued nutritive deficiency.

The nitrogen of alfalfa hay was more digestible than the nitrogen of clover hay, but the percentage of utilization in both cases was the same. This observation is equally true, whether we consider the total feces nitrogen as indigestible or whether we estimate, and consider as digestible, that fraction of the feces nitrogen which is of metabolic origin. It is possible, however, that this interesting difference which we have observed in the digestibility of the nitrogen compounds of clover and alfalfa hay without such difference in the utilization of the same, was characteristic only of the particular samples of hay involved, and not of these two roughages in general.

The proportionate elimination of sulphur in urine and feces was controlled by the amounts and kinds of feeds consumed, and not apparently by the amounts of the other mineral elements.

In rations the roughage of which was clover hay the urinary sulphur was commonly one-third or one-fourth as great in amount as the feces sulphur, but gluten feed, which is rich in sulphur, possesses a marked tendency to increase the proportion of urinary sulphur, as does also alfalfa hay. With heavy consumption of alfalfa hay the urinary sulphur was always high, and sometimes exceeded the quantity in the feces.

Approximately three-fourths of the urinary sulphur was in the form of sulphates. Ethereal sulphates in all cases exceeded inorganic sulphates in amount, but the relative amounts of these two groups of compounds were subject to such very wide variation, in accord with the state of metabolism of the individual animal, that no specific statement is possible, regarding this matter, which applies in the several experimental periods.

Silicon.—An extensive metabolism of silicon was demonstrated in the first experiment of this series. From 15.617 to 24.925 grams per day of this element was retained during the feeding of timothy hay. The retention was much less when the roughage used was alfalfa or clover. This was in harmony with the silicon content of the rations. The urine was acid during this period of high silicon intake, but not under any other circumstances during these experiments. Silicon was found in considerable quantities in the urine, but not in weighable amounts in milk. Its presence in milk, however, has been demonstrated. Approximately half of the mineral acidity of the ration containing timothy hay was due to silicon.

Calcium, Magnesium and Phosphorus.—These elements are associated in metabolism because of the limited solubility of their compounds, and because they occur in the animal body, in milk, and in the excreta largely in chemical combination. The most unexpected results of this investigation have to do with this group of elements.

The rations used, considered as a group, were characterized by high contents of calcium, magnesium and phosphorus. The amounts of each present in the feed greatly exceeded those in the milk produced, except in one instance, that of the ration containing timothy hay, in the first experiment. Here the calcium intake was obviously low.

In all cases the intake of magnesium exceeded the apparent requirement by a much larger proportion than did the intake of calcium and phosphorus.

The most prominent fact regarding the metabolism of these three elements is the lack of direct bearing of the intake upon the balance; that is, there was a conspicuous failure of the cows to utilize these constituents of the rations, when negative balances indicated that the apparent physiological need for them was not fully satisfied. Thus, in spite of the fact that the intake of these elements was usually greatly in excess of the apparent requirement, the outgo of calcium exceeded the intake in every one of the forty-two balances. The basal rations were naturally rich in these elements, and the supplemented ones contained large additional amounts of these nutrients in the shape of readily available inorganic compounds.

While there was calcium loss in every case, there was magnesium loss in 95 percent and phosphorus loss in only 79 percent of the balances. A considerable body of knowledge indicates that these negative balances of calcium, magnesium and phosphorus signify the withdrawal of these elements from the skeleton, and since there was, in most cases at least, a superabundance of these nutrients in the rations in readily absorbable form it is apparent that the method of transfer of these nutrients from the bones to the mammary gland is such that the supplies present in the skeleton are more readily available, in part at least, than those directly absorbed from the alimentary tract, and that liberal milk production involves the withdrawal of calcium, magnesium and phosphorus from the skeleton in quantities somewhat greater than the skeleton is able to assimilate from the blood-stream, with the result that under these circumstances, without regard to the nitrogen metabolism, negative balances of calcium, magnesium and phosphorus must ordinarily prevail.

In this series of experiments there is some evidence of a relation between calcium intake and retention, but increased intake is not followed closely by increased storage—the irresponsiveness of cows to the increased calcium intake is especially prominent. This poor utilization of calcium was shown to be due not to lack of proper proportion between calcium, magnesium and phosphorus in the rations, nor to difficult solubility of the calcium compounds, nor to deficiency of common salt. The one pronounced case of deficient supply of calcium was in the timothy hay ration; otherwise very imperfect utilization associated with superabundant intake commonly prevailed.

Regarding the elimination of this group of elements from the body, calcium was present in the alkaline urine in exceedingly small quantities, but its amount was slightly increased where timothy hay was fed and the urine became acid.

Extremely little phosphorus also was usually present in the urine, though the amount was slightly increased by the timothy hay ration above referred to. Unlike calcium, however, phosphorus was sometimes much increased in the urine by general physiologic disturbance. A larger proportion of the outgoing phosphorus was contained in the milk and a smaller proportion occurred in the feces than was true in regard to calcium; that is, a larger proportion of the phosphorus than of the calcium of the rations was utilized.

Magnesium was always contained in the urine in greater quantities than calcium or phosphorus, but the feces contained much more magnesium than did the urine, sometimes two-and-a-half or three times as much; at other times, on other diets, nineteen times as much.

It thus appears that there is a marked difference in the responsiveness of milch cows to the intake of protein and energy-producing foods on the one hand and these mineral nutrients on the other. It may be that negative balances of calcium, magnesium and phosphorus are characteristic of the early part of the period of lactation, without regard to the amount of milk produced, the inherited impulse of the cow to produce milk exceeding her capacity to assimilate the corresponding amounts of these materials, but it seems to us unlikely that this mineral overdraft occurs except as a result either of the selective intensification of the natural tendency of the cow to produce milk—the digestive and assimilative functions failing to meet the demands upon them—or in cases of actual mineral deficiency in the ration.

A fair question to ask in connection with this investigation is whether the whole plane of mineral intake was not so high as to render the negative balances without practical significance, in that they do not involve an approach to a critical state of mineral impoverishment, and that these losses might cease after a time, with the reestablishment of equilibrium on a lower plane of nutrient reserves. There are numerous instances in which we have suggested such an interpretation of negative balances, and in many cases it is impossible to say whether the facts should be so explained or not, but in regard to calcium, with its invariably negative balances, it seems to us that the case is more clear. In the timothy hay ration, containing no legumes, there is an actual deficiency of calcium; and in other rations with their much higher calcium contents we have an unexplained inefficiency of utilization.

That the negative calcium balances of the early part of the period of lactation become positive, after a time, when the milk-flow has become sufficiently reduced, is indicated by the work of Albert Anger.* Further evidence on this subject is needed, however, on account of certain unsatisfactory details of procedure in Anger's work, which render the results to a certain extent questionable.

The Balance of Mineral Acids to Bases in the Rations.—The balance of mineral acids to bases in the rations, as computed from their chemical analysis, always showed an excess of base except in the one case where timothy hay was the only roughage fed, and where the ration contained no feed of leguminous origin. Here, as has been previously remarked, the urine was acid. From this result we infer that in the absence of leguminous roughage the ration of the milch cow may be undesirably acid in character. The general

*Anger, A., Ueber den Umsatz und Ansatz der Aschenbestandtheile, vornehmlich von Kalk, Magnesia, Kali und Phosphorsaure, bei milch kuhen, Inaug Diss., Heidelburg, 1898.

failure of students of nutrition to recognize this possibility is due to overlooking the fact of the high silicon content, and the absorbability of certain silicon compounds of feeds, especially of roughages of the grass family.

INDEPENDENCE OF INDIVIDUAL MINERALS IN THEIR METABOLISM

Another point made clear by this investigation is the large measure of independence which exists in the metabolism of the several elements studied; thus calcium, magnesium and phosphorus, on account of their occurrence together in such quantities in the skeleton, might be expected to be closely bound together in metabolism, but in this investigation we found calcium and magnesium to an appreciable extent independent of each other, while phosphorus, by virtue of the considerable quantities contained in the soft parts, was sometimes retained during periods in which both calcium and magnesium were lost. The independence observed in the metabolism of nitrogen and sulphur has already been remarked upon, as has also the general independence of the nitrogen and mineral metabolism.

The quantitative character of metabolism, therefore, appears to be highly variable; the body does not gain nor lose in each of its constituents at a definite proportional rate; rather, it exhibits a surprising degree of metabolic adaptability. Under ordinary circumstances the nutrient reserves and physiologic safeguards constitute an extensive field of compensation and adjustment between the organism and its environment, serving to protect from injurious incidents and to permit the enjoyment of benefits accruing from favorable circumstances, the ultimate dependence of the integrity of metabolism upon each and every nutrient becoming fully manifest only with the exhaustion of reserves and the overtaxing of physiologic safety provisions.

DISCUSSION OF PRACTICAL BEARINGS

The chief interest of the practical agriculturist in such an investigation as this one which we discuss is the bearing of the results upon the business of dairy cattle management. The critical experimenter realizes full well, however, that the drawing of such conclusions is the most difficult part of his task, for the reason that after having studied a single factor among the many which compose the practical situation he is not in possession of evidence sufficient really to warrant such conclusions as his constituency desires. The environment of the animal is composed of such a complication of influences that it is impossible to determine the proportionate contribution of each of them, especially of the obscure and intricate facts of mineral metabolism. Under these circumstances we can not do better than to call attention to our main findings, to outline the general conditions as to related affairs in practice, and to make such suggestions in regard to dairy cattle management as seem to be useful and in harmony with the evidence, without implying or attempting to demonstrate a complete dependence of these suggestions upon the evidence here adduced.

We have determined (1) that liberal milk production involves a certain degree of impoverishment of the skeleton in mineral substance, (2) that rations which contain no leguminous roughage are apt to be definitely lacking in mineral nutriment, especially calcium, (3) that the response of heavily-producing cows to liberal intake of mineral nutriment is remarkable for its inefficiency, it being apparently impossible by any method of feeding entirely to prevent loss of calcium, at least during the early part of the period of lactation, and (4) that the mineral constituents of the skeleton appear to be more readily available for use in milk secretion than are nutrients directly absorbed from the ration.

It is true that most of these losses of minerals observed were small, in comparison with the extent of the cow's mineral stores; and that these overdrafts may be restored, under favorable conditions, during the latter part of the period of lactation when the milk-flow has fallen off to such extent that the withdrawal of minerals from the skeleton is no longer required.

The practical significance of these losses is thought to lie in the fact that even though small they signify just so much decrease in the capacity of the animal to meet further like demands, and that they may come to possess added significance during the unfavorable conditions which frequently exist in practice when the slight loss observed under optimum conditions may become a larger one, and when the effects of any loss may be magnified by the critical character of the animal's nutritional situation.

What should these facts mean to the dairy farmer? Let us consider certain general relations of the growth of animals to the mineral nutrients of their food.

The idea of the dependence of the skeletal development of livestock on the composition of the forage, and of the latter, in turn, on the composition of the soil, is one which long ago became a part of the system of belief of thoughtful stock husbandmen; to this day, however, the subject has not been submitted to thoroughgoing experimental inquiry, though many fragments of evidence have been recorded, and an indefinite number of more or less scientific articles on the subject have appeared, especially in the agricultural press. We have not made a thorough review of the voluminous literature, but a considerable number of references may be found in our Review of the Literature of Phosphorus Compounds in Animal Metabolism (Technical Bulletin No. 5, Ohio Agricultural Experiment Station, pages 535 and 536).

One of the more interesting studies now in progress is that of Kisaku Kitta of the Imperial Livestock Experiment Station, at Chiba, Japan. This investigation is demonstrating marked differences in the composition of the grasses from two experimental farms, located on different types of soil, which differ in composition in significant ways; and the feeding to horses of the grasses grown upon these soils seems consistently to affect the skeletal development.

Similar observations have been made in Australia. Hilda Kincaid has found that the native vegetation of Victoria is characteristically poor in phosphorus. (Proc. Roy. Soc. Victoria, 23 (N. S.) Pt. II, 1911.) E. W. Murphy, also of Victoria, writes on the prevention of rickets, "cripples" and paralysis by the fertilization of pastures. According to Murphy these and related disorders are to be found in the livestock of Victoria, New South Wales, Tasmania and New Zealand. Milking cows and growing stock exhibit a comparatively high susceptibility. On the Mornington Peninsula, as the land was fenced and the range restricted, it was found impossible, in certain situations, to maintain cattle in good condition on the natural vegetation; after the improvement of the forage by fertilization with mineral and animal fertilizers, however, it became possible to maintain livestock in the best of condition (Journal Department of Agriculture, Victoria, XV, Part 8, August 10, 1917).

In our own country malnutrition of the bones of cattle is reported as occasionally though infrequently present in many regions; as quite prevalent in southern Alabama and also in some parts of Florida, Mississippi and the state of Washington.

In the Alabama situation the soil is sandy, and contains very little lime. The cattle referred to are on the ranges where legumes if present at all are scarce. As soon as these cattle are put on velvet beans and other farm crops, in the fall, they recover and come out in good condition. Here it is noticeable that cows are more commonly affected than are suckling calves, but the disorder is not entirely confined to the cows.

In the state of Washington this disorder is found in the western, rainy section, where the soils are reported to be very poor in lime.

This disorder has been found in a great variety of situations, but most commonly in regions of infertile, sandy soils, or soils of granitic origin, especially if these be worn by long cropping, with insufficient fertilization. It may also be caused by close confinement and lack of roughage. Calves so treated have reached such a state of mineral impoverishment that the long bones of the legs have been fractured as the result of sudden fright.

The collection of evidence in this field is rendered difficult, and the results of uncertain value, by the confusion which exists as to the distinction between simple malnutrition of the bones, due to insufficient mineral intake, and the several diseases affecting the skeleton in which malnutrition of the bones may be a contributory cause. Clear-cut differentiation within this group of disorders awaits their further study.

The most familiar demonstration of the effects of the mineral draft of milk secretion on the natural organism is that furnished by the brood sow suckling a large litter of pigs while subsisting on a ration composed in the main of grain or grain products. Probably all experienced swine-herdsmen have seen sows "break down" under these conditions. This crippling is due in some cases to weakened tendinous attachments, but often to actual fracture of the leg bones.

Important factors in determining the susceptibility of the several kinds of farm animals to mineral starvation are (1) the extent of the mineral stores of the skeleton as determined by age, breed and species, (2) the rate and duration of milk production and (3) the mineral content of the ration.

In the literature we find several references to the prevalence of malnutrition of the bones following seasons of excessive heat and drouth. This condition bears some relation to the deficient mineral content of the forage, due to subnormal transpiration of mineral-bearing moisture from the soil. By laboratory studies we have found that there may be such an effect of limited water supply on the mineral content of plants, but we do not find any general opinion among those best qualified to know that drouth leads directly to malnutrition of the bones.

We must not lose sight of the fact, however, in connection with the comparative rarity of acute malnutrition of the bones in cattle, that our anxiety is not especially to feed in such manner as to prevent this malady, any more than our personal anxiety at meal-time is to escape death by starvation; rather, it is our desire so to feed our animals, as well as ourselves, as to maintain a maximum state of efficiency, which in the one case is as far removed from malnutrition of the bones as in the other from general starvation.

Among other disorders of the nutrition of cattle which have been mentioned by our correspondents, in connection with the subject of mineral metabolism, but which have not been shown to relate directly to the results of this investigation are "alkali disease," reported from South Dakota and California, "Grand Traverse disease" from Michigan, and the hairlessness of the young at birth, reported as associated with goiter in Montana, Washington, Alaska and other states.

In an effort to gain an understanding of the bearings of the facts of mineral metabolism on the practical behavior of dairy cows we have carried on a systematic correspondence with professors of dairy husbandry and veterinary science. From this source we have reached a fair understanding of the prevailing intelligent opinion on this subject in this country, but it is well enough to understand that such inquiries are better calculated to raise questions than to settle them, and that no elaboration of criticism or treatment of mere records of opinion can give to such results the character of conclusions from fully controlled experimental investigations.

But however this may be, there is general agreement that sterility is common among milch cows, wherever large numbers of them are brought together in an intensive program of feeding, breeding and milk production, and that this failure to breed is becoming more prevalent. Much current opinion relates this situation to contagious abortion alone, but others, who are considered as competent to judge of the facts, are positive that a large proportion of the cases must be due to the operation of some other important and unexplained factor. It is reported, on the best of authority, that whole herds will fail to breed, during a limited period, apparently because of their state of nutrition, there being no indication of contagious abortion. At the same time there is a belief, so prevalent that we may regard its truth as established, that failure to breed is decidedly common, though by no means invariable, after especially heavy and protracted milk production, which, we have learned, calls for overdrafts at the mineral bank.

It is also the prevailing opinion that failure to breed is more prevalent among dairy than among beef cows, and that the higher the dairy development of the cow the more frequently will there be difficulty in getting her to conceive. It is the prevailing belief that this physiological disturbance is an effect of the combination of intensive milk production, heavy feeding, and the restraints of an unnatural environment; the delayed breeding of the heavy producer, especially as handled in feeding for records of sustained production, is thought also to be a factor.

It is also generally understood that gross overfeeding, overallowance of protein, or any marked lack of balance in the ration, due to excessive proportion of certain feeds, even though they possess great nutritive value, may cause abortion and temporary or permanent sterility; thus cottonseed meal, peanuts and velvet beans, when used to excess, are believed to cause these disorders; and even alfalfa, the very cream of forage plants, has been the cause of much complaint, on the same score, when it is used to the practical exclusion of other feeds. The case against alfalfa has not been established, but many men whose interests are involved consider this still a live problem. Of course this is quite without bearing on the normal use of alfalfa. No roughage has a greater general usefulness. In its content of mineral nutriment it ranks at least among the highest, and it has the reputation of producing large bone in calves, colts and poultry.

It has been reported that dairymen who use slacked lime to sweeten the mangers after feeding corn silage have less trouble with sterility than do others who do not follow this practice.

It is also well known that the partial starvation which is caused by seasons of drouth, food shortage and other hardships is followed by increases of sterility and abortion. Any general injury of forage crops which results in loss of vitality in the cattle has like consequences.

That the composition of the forage and drinking water, as related to the composition of the soil, has constituted an important factor in the evolution of the breeds of livestock is an idea advanced by Brown ("British Sheep Farming") in 1870. Brown's classification of the ancient breeds of British sheep in relation to the geological character of the soil was modified, elaborated and discussed at length by McConnel in his "Elements of Agricultural Geology." McConnel classified these breeds of sheep into five groups, the general characters of which he believed had been determined by the alluvial, chalk, limestone, sandstone and archaean (mountain) types of soil upon which they had developed.

The character of wool as related to the soil upon which the sheep were grown has also been remarked upon by Bakewell, and by Youatt, and also by Rogers (Six Centuries of Work and Wages).

From the results of this investigation, therefore, and in the light of our general understanding of the subject of mineral metabolism, we would offer the following recommendations to the dairy farmer, having in mind the provision of the full mineral requirement of maintenance, growth, reproduction and milk secretion, and the protection of the cow, especially against the possibility (1) of diminution of milk secretion, (2) of disturbance of reproduction, (3) of depletion of mineral reserves and (4) of malnutrition of the bones.

Get your farm into a high state of fertility, and treat the soil, if necessary, so that it will grow legumes; then grow them, making as liberal use as is profitable of fertilizers containing calcium and phosphorus.

Consider with care your meadows and pastures; they are often neglected; if the soil is not rich, the mineral nutrients in pasture grass may be doubled by fertilization.

Build up the mineral reserves of your cattle by growing them largely on leguminous roughage or on pastures containing an abundance of legumes; and allow them exercise, as much as they incline to take. Muscular activity increases the avidity of bone cells for mineral salts.

Feed leguminous roughage during milk production; and give the cow a chance to refund mineral overdrafts by continuing the liberal feeding of leguminous roughage during the latter part of the period of lactation, and during the dry period, before the birth of the next calf.

Use as large a proportion of roughage in the ration as seems practical and profitable.

If you are short of leguminous roughage and must depend on corn fodder, straw, or hay made from grasses, or if on any other account there is reason to believe that your cows are not receiving proper bone food, give them bone flour. If they are already in good order there will be no marked change in condition, but the feeding of bone flour will help to keep them at their best, and is good insurance.

We have not yet determined the best method of feeding bone flour. We have fed 2½ ounces per head per day mixed with the grain, but it may be better, and all that is necessary, to allow cattle free access to this preparation. This we hope to learn at an early date.

The results of this investigation, therefore, do not indicate the desirability of radical departure from those methods of dairy cattle management which are practiced by the most successful dairymen, but they do illuminate the field in a way to add to our resourcefulness in meeting the exigencies of practice by rational and discriminating modifications of procedure. Furthermore, the facts, as we are finding them, contribute to the weight of evidence in favor of good general agricultural practice.

TABLE I.—TOTAL FOODS CONSUMED AND MILK PRODUCED, AND LIVE WEIGHTS OF COWS—Grams.

Cow No. and days in period		Foods consumed									Milk produced	Weights of cows	
		Corn	Cotton-seed meal	Linseed oilmeal	Wheat bran	Alfalfa hay	Common salt	Precipi-tated bone flour	Calcium lactate	Calcium chloride		Average first five daily weights	Average last five daily weights
PERIOD I												*Kilos*	*Kilos*
1	20	99770	18140	18140	9070	145120	840.0	....	....	....	461366	442.8	438.0
2	8	39738	7225	7225	3613	56860	334.8	....	....	....	155113	416.0	....
3	20	99770	18140	18140	9070	145120	840.0	....	....	... .	404884	489.9	486.3
4	20	99770	18140	18140	9070	145120	840.0	1400	....	....	416821	424.3	419.6
5	20	99770	18140	18140	9070	145120	840.0	1400	....	....	432844	422.2	422.5
6	20	99770	18140	18140	9070	145120	840.0	1400	....	....	425222	499.1	501.2
PERIOD II													
1	20	99770	18140	18140	9070	163280	840.0	....	2225.040	....	465229	444.8	451.3
2	10	37428	6805	6805	3403	72560	420.0	....	556.260	....	151419	....	381.4
3	8	33672	6122	6122	3061	54199	304.5	. ...	750.951	....	148417	497.2	....
4	16	79816	14512	14512	7256	130624	672.0	.. ..	....	640.000	352026	422.4	424.5*
5	20	99770	18140	18140	9070	163280	840.0	....	....	800.000	453928	428 9	429.3
6	20	99770	18140	18140	9070	163280	840.0	....	.. ..	800.000	441716	508.4	518.6

*Average of two weights only.

TABLE II—AVERAGE DAILY FOODS CONSUMED AND MILK PRODUCED—Grams.

Cow No. and days in period		Foods consumed: Corn	Cottonseed meal	Linseed oilmeal	Wheat bran	Alfalfa hay	Common salt	Precipitated bone flour	Calcium lactate	Calcium chloride	Milk produced
PERIOD I											
1	20	4989	907	907	454	7256	42	....	....	....	23068
2	8	4967	903	903	452	7108	41.850	....	....	....	19389
3	20	4989	907	907	454	7256	42	....	....	....	20244
4	20	4989	907	907	454	7256	42	70	....	....	20841
5	20	4989	907	907	454	7256	42	70	....	....	21642
6	20	4989	907	907	454	7256	42	70	....	....	21261
PERIOD II											
1	20	4989	907	907	454	8164	42	....	111.252	....	23261
2	10	3743	681	681	340	7256	42	....	55.626	....	15142
3	8	4209	765	765	383	6775	38.063	....	93.869	....	18552
4	16	4989	907	907	454	8164	42	....	....	40	22002
5	20	4989	907	907	454	8164	42	....	....	40	22696
6	20	4989	907	907	454	8164	42	....	....	40	22086

TABLE III—COMPOSITION OF FOODS (Percent)

Food	Dry matter	Ether extract	Crude fiber	Nitrogen	Protein	Nitrogen-free extract	Ash	Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus	Silicon
Corn	86.19	4.27	1.51	1.384	8.65	70.54	1.22	0.001	0.313	0.009	0.107	0.093	0.032	0.245	0.014
Cottonseed meal	91.24	4.50	19.04	3.762	23.51	39.61	4.58	0.003	1.250	0.151	0.401	0.230	0.030	0.667	0.109
Linseed oilmeal	90.55	6.89	6.35	4.811	30.07	41.45	5.79	0.049	1.245	0.353	0.486	0.359	0.042	0.835	0.207
Wheat bran	89.54	4.19	7.49	2.380	14.88	61.12	1.86	0.039	1.583	0.103	0.587	0.173	0.065	1.574	0.023
Grain mixture (Per. II*)	89.14	4.80	4.10	2.444	15.28	62.25	2.71	0.024	0.663	0.082	0.230	0.186	0.030	0.482	0.052
Alfalfa hay (Per. I)	89.70	2.60	31.59	2.093	13.08	36.28	6.16	0.099	1.278	1.146	0.266	0.181	0.051	0.204	0.202
Alfalfa hay (Per. II)	91.46	2.58	27.45	2.562	16.02	35.94	9.48	0.039	3.018	1.225	0.156	0.260	0.319	0.241	0.444
Sodium chloride	....	....	....	....	....	....	....	39.209	....	....	....	....	60.452	....	....
Precipitated bone flour	....	0.15	....	0.136	....	....	....	0.259	....	24.453	0.633	0.355	2.002	16.182	....
Calcium lactate (Lot 2)	....	....	....	0.191	....	....	....	0.075	0.027	13.191	0.023	....	0.245	....	0.047
Calcium lactate (Lot 3)	....	....	....	(0.050)	....	....	....	(0.059)	(0.013)	13.293	....	(0.020)	(0.085)	....	0.178
Calcium lactate (Lot 4)	....	....	....	(0.050)	....	....	....	(0.059)	(0.013)	14.048	....	(0.020)	(0.085)	....	0.063
Calcium lactate (Lot 6)	....	....	....	0.050	....	....	....	0.059	0.013	14.249	....	0.020	0.085	....	0.087
Calcium chloride	....	....	....	....	....	....	....	0.051	0.013	35.375	....	....	64.543	....	....

*This analysis represents all grains fed in Period II.

TABLE IV.—COMPOSITION OF MILK (Percent)

Cow No.	Moisture	Nitrogen	Protein (N x 6.37)	Ether extract	Ash	Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus
PERIOD I												
1	88.36	0 476	2.975	2.792	0 759	0.037	0.175	0.128	0.012	0.028	0.084	0.094
2	87.46	0.493	3.081	3.545	0.705	0.034	0.153	0.125	0 012	0.034	0.079	0.101
3	88.96	0.441	2 756	2 702	0.732	0.040	0.179	0.103	0.013	0 029	0 096	0 097
4	87.66	0.446	2.788	3.363	0 679	0.035	0.142	0.121	0.014	0.030	0.071	0.085
5	88.01	0.435	2.719	2.946	0.674	0.034	0 151	0.112	0 014	0.032	0 058	0 088
6	88 42	0.453	2 831	2.763	0 744	0.037	0.171	0.121	0.013	0.032	0.076	0.100
PERIOD II												
1	88.52	0.489	3 056	2.618	0.770	0.033	0.179	0 126	0.013	0.033	0.094	0 095
2	87.59	0 505	3.156	3.372	0.696	0.025	0.159	0 116	0.012	0.034	0 090	0 093
3	88.68	0.450	2.813	2.848	0 721	0 033	0.174	0.104	0.014	0 032	0.092	0.096
4	87.85	0.450	2.813	3.195	0.664	0.027	0.150	0.116	0.014	0.029	0.068	0.087
5	88.12	0.442	2.763	2 866	0 656	0.023	0.154	0.109	0 015	0 030	0.060	0.090
6	88.56	0.455	2 844	2 600	0.716	0.029	0.179	0.117	0.013	0 030	0 074	0.101

TABLE V.—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
PERIOD I														
1	12864.72	524.02	2631.78	309.478	1934.16	7164.42	24.355	138.188	88.671	35.368	23.911	31.628	47.787	18.313
2	12704.80	518.74	2583.56	305.699	1910.55	7091.45	24.147	136.099	86.950	34.904	23.597	31.450	47.342	17.999
3	12864 72	524.02	2631.78	309.478	1934.16	7164.42	24.355	138.188	88.671	35.368	23 911	31.628	47.787	18.313
4	12864.83	524.13	2631.78	309.573	1934.16	7164.42	24 537	138 188	105 788	35.811	24.160	33 029	59.114	18.313
5	12864.83	524.13	2631.78	309.573	1934.16	7164.42	24 537	138.188	105.788	35.811	24.160	33 029	59.114	18.313
6	12864 83	524.13	2631.78	309.573	1934.16	7164.42	24.537	138.188	105.788	35 811	24.160	33.029	59.114	18.313
PERIOD II														
1	13936.35	558.92	2538.52	386.598	2416.59	7451.00	21.432	294.503	121 319	29.393	34.722	53.751	54.608	40.077
2	11490.37	448.51	2214.97	318.978	1994.25	5996.70	20.608	255.078	101.276	23 803	28.991	50.204	43.691	35.065
3	11654.87	468 66	2110.74	323.318	2020.80	6245.89	19.075	245.069	100.503	24.631	28.995	46.631	45 802	33.305
4	13936.35	558.92	2538 52	386.499	2416.59	7451.00	21.381	294.488	120.109	29.384	34.708	79.412	54.608	39.988
5	13936.35	558 92	2538.52	386.499	2416.59	7451.00	21.381	294.488	120.109	29.384	34.708	79.412	54.608	39.988
6	13936 35	558 92	2538.52	386.499	2416.59	7451.00	21.381	294.488	120.109	29.384	34.708	79.412	54.608	39.988

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

Cow No.	Nitrogen	Ether extract	Ash	Sodium	Potassium	Calcium	Magnesium	Sulphur	Phos-phorus	Chlorine
PERIOD I										
1	109.804	644.059	175 040	8 512	40.369	29.504	2 860	6.436	21 776	19.308
2	95.588	687 340	136.654	6.650	29.665	24 198	2 385	6 670	19.525	15.356
3	89.276	546.993	148.166	7 996	36.237	20 770	2 713	5 790	19 677	19.394
4	92.906	700 547	141.338	7.208	29 580	25.185	2 937	6 208	17.665	14.748
5	94.143	637.573	145 759	7.358	32.679	24.153	3.116	6.839	19.067	12 617
6	96.312	587 441	158.097	7 909	36.356	25 662	2 658	6 718	21 155	16.201
PERIOD II										
1	113.746	608.973	178.993	7,746	41.637	29 332	3 117	7.583	22 005	21.819
2	76 467	510 588	105.373	3.725	24.076	17 489	1 772	5.163	14.021	13.567
3	83.484	528.361	133.834	6.122	32.280	19.331	2.616	5.844	17.810	17.105
4	99.009	702.964	146.137	5 831	33.003	25.522	2 992	6.313	19 054	14.961
5	100.316	650.467	148 954	5.220	34.952	24 829	3 336	6 854	20 426	13.618
6	100.491	574.236	158.025	6.361	39 534	25 885	2.849	6.560	22 263	16.255

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

Cow No.	Nitrogen	Sodium	Potassium	Calcium	Magnesism	Sulphur	Chlorine	Phosphorus
Period I								
1	106.767	6.881	90.719	0.060	4.840	7.851	4.551	0.147
2	119.918	14.879	92.530	0.068	6.558	9.062	8.529	0 623
3	116.363	8.653	87.606	0.265	3.907	8.975	4.060	0.162
4	104.465	2.958	88.771	0.370	3.990	7 614	6.701	0.109
5	106.187	10.270	90.105	0.267	3.439	8 017	6.567	0.108
6	112.703	9.646	83.168	0.027	6.920	8.851	11.685	0.154
Period II								
1	128.680	11.425	219.863	0.146	2.808	13.215	19.877	0 176
2	127.759	12.780	203.499	0.027	2.740	11.938	25.384	0.646
3	152.372	10.353	192.414	0.170	1.767	14.121	21.530	0.238
4	138.845	8.070	226.056	0.240	2.061	13.445	47.031	0.125
5	142.392	10.308	228 645	0.241	1 451	14 216	51.950	0.140
6	148.986	9.479	223.650	0.131	5.380	14.802	51.095	0 162

TABLE VIII.—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
PERIOD I														
1	27,484	4 746.487	186.891	1,647.391	105.951	662 200	1,887 766	2 858	17.507	67 034	30.920	12.503	9.042	32.321
2	27 134	4,384.854	183.507	1,601.720	95 756	598.468	1,654.116	3.419	17.203	66.207	26.863	12.590	12.455	28.681
3	27 379	4 536.700	188.614	1,551.294	109.817	686.364	1,723 289	0.712	19.905	80.029	28.858	12.649	9.199	33 457
4	28 566	4,907.639	199.991	1,564.560	121 863	761.655	1,936.946	7.941	26.338	90.040	28.080	13.283	11.998	45 220
5	26 667	4,682.725	177.656	1,585 887	112.481	703.022	1,802.289	4.400	17.760	86 561	29.414	12.480	13.147	40.987
6	27,506	4 557 744	185 198	1,570.318	105.513	659 456	1,742.010	2 393	17.796	83.096	26.351	12 598	9.270	38.481
PERIOD II														
1	29 886	4 778.772	177.702	1,455.448	117.930	737.078	1,961.448	2 331	22 265	100.477	26.658	14.315	12.522	33.532
2	24 576	3 789.619	158.073	1,169 572	93.905	586.900	1,482 842	2.556	18 383	91 472	20.202	12 067	11.993	29 442
3	26 030	4 011.223	163.182	1 238 507	99 773	623.575	1,577.028	1 510	20 486	97.508	24.026	12 130	9 709	31 861
4	29 727	4,842.528	223.696	1 368.037	124.705	779.412	1 993.374	3 954	29 014	106.007	27.171	14 655	15.072	37 397
5	29 538	4 655.189	178 350	1.367.809	118.418	740.104	1 892 086	1 920	24 221	103.738	26 998	14.237	12.583	35.062
6	28 737	4 497.341	188 543	1 436 563	113 166	707.304	1 724 680	2 500	22 185	102 505	24 139	13.564	10.202	33.019

TABLE IX.—PERIOD I: AVERAGE DAILY RATIONS AND BALANCES OF MINERALS AND NITROGEN (Grams)

Cow No.	Average daily milk yield	Average daily ration	Distinguishing features of rations	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
1	23,068	Corn, 4989; cottonseed meal, 907; linseed oil-meal, 907; wheat bran, 454; alfalfa hay, 7256; salt, 42	Basal ration	24.355 8.512 6.881 2.858 + 6 104	138.188 40.369 90.719 17.507 — 10.407	88.671 29.504 0.060 67.034 — 7.927	35.368 2.860 4.840 30.920 — 3.252	23.911 6.436 7 851 12.505 — 2.881	31.628 19.308 4.551 9.042 — 1.273	47.787 21.776 0.147 32.321 — 6.457	309.478 109 804 106.767 105.951 — 13.044
2	19,389	Corn, 4967; cottonseed meal, 903; linseed oil-meal, 903; wheat bran, 452; alfalfa hay, 7108; salt, 41.850	Basal ration	24.147 6.650 14.879 3.419 — 0.801	136 099 29.665 92.530 17.203 — 3 299	86.950 24.198 0.068 66.207 — 3.523	34.904 2.385 6.558 26.863 — 0.902	23 597 6 670 9.062 12.590 — 4.725	31.450 15.356 8.529 12.455 — 4.890	47.342 19.525 0.623 28.681 — 1.487	305.699 95.588 119 918 95 756 — 5.563
3	20,244	Corn, 4989; cottonseed meal, 907; linseed oil-meal, 907; wheat bran, 454; alfalfa hay, 7256 salt, 42	Basal ration	24 355 7 996 8 653 0 712 + 6.994	138.188 36 237 87.606 19.905 — 5.560	88.671 20.770 0.265 80.029 —12.393	35.368 2.713 3.907 28 858 — 0.110	23.911 5.790 8.975 12.649 — 3.503	31.628 19.394 4.060 9.199 — 1.025	47.787 19.677 0.162 33.457 — 5.509	309.478 89.276 116.363 109.817 — 5.978
4	20,841	Corn, 4989; cottonseed meal, 907; linseed oil-meal, 907; wheat bran, 454; alfalfa hay, 7256; salt, 42; precipitated bone flour, 70	Basal ration plus precipitated bone flour	24.537 7.208 2.958 7.941 + 6.430	138.188 29.580 88.771 26.338 — 6.501	105 788 25.185 0.370 90.040 — 9.807	35.811 2.937 3.990 28.080 + 0.804	24.160 6 208 7.614 13 283 — 2.945	33.029 14.748 6,701 11.998 — 0.418	59.114 17.665 0.109 45.220 — 3.880	309.573 92.906 104 465 121.863 — 9.661
5	21,642	Corn, 4989; cottonseed meal, 907; linseed oil-meal, 907; wheat bran, 454; alfalfa hay, 7256; salt, 42; precipitated bone flour, 70	Basal ration plus precipitated bone flour	24.537 7.358 10.270 4.400 + 2 509	138.188 32.679 90.105 17.760 — 2.356	105.788 •24.153 0.267 86.561 — 5.193	35.811 3.116 3.439 29.414 — 0.158	24.160 6 839 8.017 12.480 — 3.176	33.029 12.617 6.567 13.147 + 0.698	59.114 19.067 0.108 40.987 — 1.048	309.573 94.143 106.187 112.481 — 3.238
6	21,261	Corn, 4989; cottonseed meal, 907; linseed oil-meal, 907; wheat bran, 454; alfalfa hay, 7256; salt 42; precipitated bone flour, 70	Basal ration plus precipitated bone flour	24.537 7 909 9.646 2.393 + 4.589	138 188 36.356 83.168 17.796 + 0.868	105.788 25.662 0 027 83 096 — 2.997	35.811 2 658 6.920 26.351 — 0.118	24 160 6.718 8.851 12.598 — 4.007	33.029 16.201 11.685 9.270 — 4.127	59.114 21.155 0.154 38.481 — 0.676	309.573 96.312 112.703 105.513 — 4.955

TABLE X.—PERIOD II: AVERAGE DAILY RATIONS AND BALANCE OF MINERALS AND NITROGEN (Grams)

Cow No.	Average daily milk yield	Average daily ration	Distinguishing features of rations	Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus	Nitrogen
				Food Milk Urine Feces Balance	Food Milk Urine Feces Balance	Food Milk Urine Feces Balance	Food Milk Urine Feces Balance	Food Milk Urine Feces Balance	Food Milk Urine Feces Balance	Food Milk Urine Feces Balance	Food Milk Urine Feces Balance
1	23,261	Corn 4989; cottonseed meal 907; linseed oil-meal 907; wheat bran 454; alfalfa hay 8164; salt 42; calcium lactate 11.252.	Basal ration plus calcium lactate	21.432 7.746 11.425 2.331 —0.070	294 503 41.637 219.863 22 265 +10 738	121.319 29.332 0.146 100.477 — 8.636	29.393 3.117 2 808 26.658 — 3.190	34.722 7.583 13.215 14.315 —0.391	53.751 21.819 19.877 12 522 —0.467	54.608 22.005 0 176 33.532 — 1.105	386.598 113.746 128.680 117.930 +26.242
2	15,142	Corn 3743; cottonseed meal 681; linseed oilmeal 681; wheat bran 340; alfalfa hay 7256; salt 42; calcium lactate 55.626.	Basal ration plus calcium lactate	20.608 3.725 12.780 2.556 +1.547	255.078 24.076 203.499 18.383 + 9.120	101.276 17.489 0.027 91.472 — 7.712	23.804 1 772 2.740 20.202 — 0.910	28.991 5.163 11.938 12.067 —0.177	50.204 13.567 25.384 11.993 —0.740	43.691 14 021 0.646 29.442 — 0.418	318.978 76.467 127.759 93.905 +20.847
3	18,552	Corn 4209; cottonseed meal 765; linseed oilmeal 765· wheat bran 383; alfalfa hay 6775; salt 38.063; calcium lacate 93.869.	Basal ration plus oalcium lactate	19.075 6.122 10 353 1 510 +1.090	245.069 32.280 192.414 20.486 — 0.111	100.503 19.331 0.170 97.508 —16.506	24.631 2.616 1.767 24 026 — 3.778	28.995 5.844 14.121 12.130 —3.100	46.631 17.105 21.530 9.709 —1.713	45.802 17.810 0.238 31.861 — 4.107	323.318 83.484 152.372 99.773 —12.311
4	22,002	Corn 4989; cottonseed meal 907; linseed oilmeal 907; wheat bran 454; alfalfa hay 8164; salt 42 calcium chloride 40	Basal ration plus calcium chloride	21.381 5.831 8.070 3.954 +3.526	294 488 33.003 226 056 29.014 + 6.415	120.109 25.522 0 240 106.007 —11.660	29.384 2.992 2 061 27.171 — 2.840	34.708 6.315 13.445 14.655 +0.293	79.412 14.961 47 031 15.072 +2.348	54.608 19.054 0.125 37.397 — 1.968	386.499 99.009 138.845 124 795 +23.940
5	22,696	Corn 4989; cotton seed meal 907; linseed oilmeal 907; wheat bran 454; alfalfa hay 8164; salt 42; calcium cloride 40	Basal rations plus calcium chloride	21.381 5.220 10.308 1.920 +3.933	294.488 34.952 228.645 24.221 + 6.670	120 109 24.829 0.241 103.738 — 8.699	29.384 3.336 1.451 26.998 — 2.401	34.708 6.854 14.216 14.237 —0.599	79.412 13.618 51.950 12 583 +1.261	54.608 20.426 0.140 35.062 — 1.020	386.499 100.316 142.392 118 418 +25.373
6	22,086	Corn 4989; cottonsed meal 907; linseed oilmeal 907; wheat bran 454; alfalfa hay 8164; salt 42; calcium chloride 40	Basal ration plus calcium chloride	21.381 6.361 9 479 2.500 +3.041	294.488 39.534 223.650 22.185 + 9.119	120 109 25.885 0.131 102 505 — 8.412	29.384 2.849 5 380 24.139 — 2.984	34.708 6.560 14.802 13.564 —0.218	79.412 16 255 51.095 10.202 +1.860	54.608 22.263 0.162 33.019 — 0.836	386.499 100.491 148.986 113.166 +23.856

TABLE XI—AVERAGE DAILY FEED, MILK AND EALANCE DATA FROM SIX COWS

Cow No.	Rations (Pounds)	Distinguishing features of ration	Milk yield	Gain or loss to the body (Grams)							
				Sodium	Potassiu m	Cacium	Magnesium	Sulphur	Clorine	Phosphorus	Nitrogen
				Intake Balance	Intake Balance	Intake Balance	Intake Balance	Intake Balance	Intake Balance	Intake Balance	Intake Balance
PERIOD I			*Lbs.*								
1	Corn 10.999; cottonseed meal 2.000; linseed oil meal 2.000; wheat bran 1.001; alfalfa hay 15.996; salt 0.9926	Basal ration	50.855	24.355 +6.104	138.188 — 10.407	38.671 —7.927	35.368 — 3.252	23.911 — 2.881	31.628 — 1.273	47.787 — 6.457	309.478 —13.044
2	Corn 10.950; cottonseed meal 1.991; linseed oilmeal 1.991; wheat bran 0.996; alfalfa hay 15.670; salt 0.0923	Basal ration	42.744	24.147 —0.801	136.099 — 3.299	86.950 — 3.523	34.904 — 0.902	23.597 — 4.725	31.450 — 4.890	47.342 — 1.487	305.699 — 5.563
3	Corn 10.999; cotton seed meal 2.000; linseed oilmeal 2.000; wheat bran 1.001; alfalfa hay 15.996; salt 0.0926	Basal ration	44.630	24.355 +6.994	138.188 — 5.560	88.671 —12.393	35.368 — 0.110	23.911 — 3.503	31.628 — 1.025	47.787 — 5.509	309.478 — 5.978
4	Corn 10.999; cottonseed meal 2.000; linseed oilmeal 2.000; wheat bran 1.001; alfalfa hay 15.996; salt 0.0926; precipitated bone flour 0.154	Basal ration plus precipitated bone flour	45.946	24.537 +6.430	138.188 — 6.501	105.788 — 9.807	35.811 + 0.804	24.160 —2.945	33.029 — 0.418	59.114 — 3.880	309.573 — 9.661
5	Corn 10.999; cottonseed meal 2.000; linseed oilmeal 2.000; wheat bran 1.001; alfalfa hay 15.996; salt 0.0926; precipitated bone flour 0.154	Basal ration plus precipitated bone flour	47.712	24.537 +2.509	138.188 — 2.356	105.788 — 5.193	35.811 — 0.158	24.160 — 3.176	33.029 + 0.698	59.114 — 1.048	309.573 — 3.238
6	Corn 10.999; cottonseed meal 2.000; linseed oilmeal 2.000; wheat bran 1.001; alfalfa hay 15.996; salt 0.0926; precipitated bone flour 0.154	Basal ration plus precipitated bone flour	46.872	24.537 +4.589	138.188 + 0.868	105.788 — 2.997	35.811 — 0.118	24.160 — 4.007	33.029 — 4.127	59.114 — 0.676	309.573 — 4.955

TABLE XI—AVERAGE DAILY FEED, MILK AND BALANCE DATA FROM SIX COWS—(Concluded)

Cow No.	Ration (Pounds)	Distinguishing features of rations	Milk yield	Gain or loss to the body (Grams)							
				Sodium Intake Balance	Potassium Intake Balance	Calcium Intake Balance	Magnesium Intake Balance	Sulphur Intake Balance	Chlorine Intake Balance	Phosphorus Intake Balance	Nitrogen Intake Balance
PERIOD II			*Lbs.*								
1	Corn 10.999; cottonseed meal 2.000; linseed oilmeal 2.000; wheat bran 1.001; alfalfa hay 17.998; salt 0.0926; calcium lactate 0.245		51 281	21.432 — 0.070	294.503 — 10.738	121.319 — 8.636	29.393 — 3.190	34.722 — 0.391	53.751 — 0.467	54.608 —1.105	386.598 +26.242
2	Corn 8.252; cottonseed meal 1.501; linseed oilmeal 1.501; wheat bran 0.750; alfalfa hay 15.996; salt 0.0926; calcium lactate 0.123	Basal ration plus calcium lactate	33.382	20 608 + 1 547	255.078 + 9.120	101.276 — 7.712	23.804 — 0.910	28.991 — 0.177	50.204 — 0.740	43.691 —0.418	318.968 +20.847
3	Corn; 9.279; cottonseed meal 1.687; linseed oilmeal 1.687; wheat bran 0.844; alfalfa hay 14.936; salt 0.0839; calcium lactate 0.207		40.899	19.075 + 1.090	245.069 — 0.111	100.503 —16.506	24 631 — 3.778	28.995 — 3.100	46.631 — 1.713	45.802 —4.107	323.318 —12.311
4	Corn 10.999; cottonseed meal 2.000; linseed oilmeal 2.000; wheat bran 1.001; alfalfa hay 17.998; salt 0.0926; calcium chloride 0.0882		48.505	21.381 + 3.526	294.488 + 6.415	120.109 —11.660	29.384 — 2.840	34.708 + 0.293	79.412 + 2.348	54.608 —1.968	386.499 +23.940
5	Corn 10.999; cottonseed meal 2.000; linseed oilmeal 2.000; wheat bran 1.001; alfalfa hay 17.998; salt 0.0926; calcium chloride 0.0882	Basal ration plus calcium chloride	50.035	21.381 + 3.933	294.488 + 6.670	120.109 — 8.699	29.384 — 2.401	34.708 — 0.599	79.412 + 1.261	54.608 —1.020	386.499 +25.373
6	Corn 10.999; cottonseed meal 2.000; linseed oilmeal 2 000; wheat bran 1.001; alfalfa hay 17.998; salt 0.0926; calcium chloride 0.0882		48.690	21.381 + 3.041	294.488 + 9.119	120.109 — 8.412	29.384 — 2.984	34.708 — 0.218	79.412 + 1.860	54.608 —0.836	386.499 +23.856

TABLE XII.—MINERALS IN DAILY RATIONS COMPUTED TO NORMAL SOLUTIONS (Cubic centimeters)

Cow No.	Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus	Silicon	Total base	Total acid	Excess base
PERIOD I											
1	1,058.9	3,534.2	4,425.8	2,908.6	1,491.2	891.9	3,079.1	1 294.2	11,927.5	6,756 4	5,171.1
2	1,049.9	3,480.8	4,339.9	2,870.4	1,471 6	886.9	3,050.4	1,272.0	11,741.0	6,680.9	5,060.1
3	1,058 9	3,534.2	4,425.8	2,908.6	1,491.2	891.9	3,079.1	1,294 2	11,927 5	6,756.4	5,171.1
4	1,066.8	3,534.2	5,280.2	2,945.0	1,506.7	931.4	3,808.9	1,294 2	12,826.2	7,541 2	52,85.0
5	1,066.8	3,534.2	5,280.2	2,945.0	1,506.7	931.4	3,808.9	1,294.2	12,826 2	7,541 2	52,85.0
6	1,066.8	3,534 2	5,280.2	2,945 0	1,506.7	931 4	3,808 9	1,294.2	12,826.2	7,541.2	52,85.0
PERIOD II											
1	931.8	7,532.0	6,055.4	2,417.2	2,165.4	1,515.8	3,518.6	2,832.3	16,936.4	10,032.1	6,904.3
2	896.0	6,523.7	5,055 0	1,957.6	1,808.0	1,415.8	2,815 1	2,478 1	14,432 3	8,517.0	5,915.3
3	829.3	6,267.7	5,016.4	2,025.6	1,808.2	1,315.0	2,951.2	2,353.7	14,139 0	8,428.1	5,710.9
4	929.6	7,531.6	5,995 0	2,416.4	2,164.5	2,239.5	3,518.6	2,826.0	16,872.6	10,748 6	6,124.0
5	929.6	7,531.6	5,995.0	2,416.4	2,164.5	2,239.5	3,518.6	2,826.0	16,872.6	10,748 6	61,24.0
6	929.6	7,531.6	5,995.0	2,416 4	2,164.5	2,239.5	3,518.6	2,826.0	16 872.6	10 748 6	61,24.0

TABLE XIII.—UTILIZATION AND ELIMINATION OF NITROGEN

Cow No.	Distinguishing features of rations	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		*Grams*	*Grams*	*Percent*	*Percent*	*Percent*
1	Basal ration	309.478	106 767	34.499	31.266	34 24
2		305 699	119 918	39.227	29 449	31.32
3		309.478	116.363	37.600	26.916	35.49
4	Basal ration plus precipitated bone flour	309.573	104 465	33 745	26.890	39 38
5		309.573	106 187	34 301	29 365	36.35
6		309.573	112 703	36.406	29.511	34.10
PERIOD II						
1	Basal ration plus calcium lactate	386 598	128.680	33.285	36.210	30 50
2		318.978	127 759	40.053	30.508	29.43
3		323.318	152 372	47 128	22 013	30 86
4	Basal ration plus calcium chloride	386.499	138 845	35.924	31.811	32.25
5		386.499	142 392	36 841	32 520	30 63
6		386 499	148 986	38 548	32.173	29.27

TABLE XIV.—COEFFICIENTS OF DIGESTIBILITY OF RATIONS

Cow No.	Distinguishing features of rations	Protein	Nitrogen-free extract	Ether extract	Crude fiber	Nutritive ratio of rations
PERIOD I						
1	Basal ration	65.76	73.65	64.34	37.40	1 : 5.52
2		68.68	76.67	64.62	38 00	1 : 5 46
3		64.51	75.95	64 01	41.06	1 : 5 83
4	Basal ration plus precipitated bone flour	60.62	72.96	61.84	40 55	1 : 5.99
5		63.65	74.84	66.10	39 74	1 : 5.84
6		65.90	75 69	64.67	40.33	1 : 5.68
PERIOD II						
1	Basal ration plus calcium lactate	69 50	73 68	68.21	42 67	1 : 4 46
2		70.57	75 27	64.76	47.20	1 : 4.44
3		69 14	74.75	65.18	41.32	1 : 4.49
4	Basal ration plus calcium chloride	67.75	73.25	59.98	46.11	1 : 4 54
5		69 37	74 61	68.09	45.37	1 : 4.55
6		70 73	76.85	66 27	43 41	1 : 4.51

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

Cow No.	Rations	Sodium Milk Urine Feces	Potassium Milk Urine Feces	Calcium Milk Urine Feces	Magnesium Milk Urine Feces	Sulphur Milk Urine Feces	Chlorine Milk Urine Feces	Phosphorus Milk Urine Feces	Nitrogen Milk Urine Feces
1	Corn; cottonseed meal; linseed oilmeal; wheat bran; alfalfa hay; salt	46.64 37.70 15.66	27.17 61 05 11.78	30.54 0 06 69.40	7.41 12.53 80.06	24.02 29.30 46.68	58.69 13.83 27.48	40 15 0.27 59.58	34 05 33.10 32.85
2	Corn; cottonseed meal; linseed oilmeal; wheat bran; alfalfa hay; salt	26.66 59.63 13.71	21.28 66.38 12.34	26.47 0.08 73.18	6.66 18.32 75.02	23.55 32.00 44.45	42.26 23.47 34.27	39.98 1 28 58.74	30.71 38.53 30.76
3	Corn; cottonseed meal; lfnseed oilmeal; wheat bran; alfalfa hay; salt	46.06 49.84 4.10	25.21 60.94 13.85	20.55 0.26 79.19	7 65 11.01 81.34	21 12 32.74 46.14	59.40 12 43 28.17	36 92 0 30 62.78	28.30 36.89 34.81
4	Corn; cottonseed meal; linseed oilmeal; wheat bran; alfalfa hay; salt; precipitated bone flour	39.81 16.34 43.85	20.45 61.35 18.20	21.79 0.32 77.89	8 39 11.40 80.21	22.90 28.09 49.01	44.09 20.04 35.87	28.04 0 17 71.79	29.10 32.72 38.18
5	Corn; cottonseed meal; linseed oilmeal; wheat bran; alfalfa hay; salt; precipitated bone flour	33 40 46.62 19.98	23.25 64.11 12.64	21.76 0 24 78.00	8 66 9.56 81.78	25.02 29.33 45.65	39 03 20.31 40.66	31.69 0.18 68.13	30.09 33.95 35.96
6	Corn; cottonseed meal; linseed oilmeal; wheat bran; alfalfa hay; salt; precipitated bone flour	39.65 48.35 12.00	26.48 60.56 12.96	23.58 0.03 76.39	7.40 19.26 73.34	23.85 31.42 44.73	43.60 31.45 24.95	35.38 0.26 64.36	30.62 35.83 33.55

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

Cow No.	Rations	Sodium Milk Urine Feces	Potassium Milk Urine Feces	Calcium Milk Urine Feces	Magnesium Milk Urine Feces	Sulphur Milk Urine Feces	Chlorine Milk Urine Feces	Phosphorus Milk Urine Feces	Nitrogen Milk Urine Feces
1	Corn; cottonseed meal; linseed oilmeal; wheat bran; alfalfa hay; salt; calcium lactate	36.03 53.13 10 84	14.67 77.48 7.85	22.57 0.11 77.32	9.57 8.62 81.81	21.60 37 63 40.77	40.24 36.66 23.10	39 50 0 31 60.19	31.56 35.71 32.73
2	Corn; cottonseed meal; linseed oilmeal; wheat bran; alfalfa hay; salt; calcium lactate	19.54 67 05 13.41	9.79 82.74 7.47	16.05 0.02 83.93	7.17 11.09 81.74	17 70 40.93 41.37	26.63 49 83 23.54	31.79 1.46 65.75	25.65 42 85 31.50
3	Corn; cottonseed meal; linseed oilmeal; wheat bran; alfalfa hay; salt; calcium lactate	34.04 57.56 8.40	13.16 78.48 8.36	16.52 0 15 83.33	9 21 6.22 84.57	18.21 44.00 37 79	35 38 44.54 20.08	35.68 0.48 63 84	24.87 45.40 29.73
4	Corn; cottonseed meal; linseed oilmeal; wheat bran; alfalfa hay: salt; calcium chloride	32.66 45.20 22.14	11.46 78 47 10.07	19.37 0 18 80 45	9.28 6.40 84 32	18.35 39.07 42.58	19 41 61.03 19.56	33.68 0 22 66.10	27.31 38.30 34 39
5	Corn; cottonseed meal; linseed oilmeal; wheat bran; alfalfa hay; salt; calcium chlorde	29 92 59.08 11.00	12.14 79.44 8.42	19.27 0.19 80 54	10.50 4 56 84.94	19.41 40 26 40 33	17 43 66.47 16.10	36 72 0.25 63.03	27 78 39.43 32.79
6	Corn; cottonseed meal; linseed oilmeal; wheat bran; alfalfa hay; salt; calcium chloride	34.68 51.69 13.63	13.85 78.37 7.78	20.14 0.10 79.76	8.80 16.62 74 58	18.78 42.38 38.84	20 96 65.88 13.16	40.16 0.29 59.55	27.71 41.08 31.21

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