THE ACID-BASE BALANCE IN ANIMAL NUTRITION

III. Effect of Addition of Alkalies to the Ration on Growth and Well-being of Swine

By Alvin R. Lamb and John M. Evvard

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CHEMISTRY AND
ANIMAL HUSBANDRY SECTIONS

AMES, IOWA
SUMMARY

Previous results obtained from a study of the ability of swine to grow and reproduce on a high acid ration are discussed in relation to the work of others. The significance of a similar test of the ability of swine to ingest and excrete large quantities of alkali during the growing period is stated, and the results are reported of an experiment in which sulfuric acid, sodium hydroxide, sodium carbonate and sodium sulfate were fed. These materials were added to a basal ration of corn, tankage, and wheat middlings. The acid-fed lot remained in very thrifty condition and made economical gains until the daily intake was increased well above 500 cc. normal solution. Judging by their performance and appetite during Periods 5 and 7 the lot receiving sodium hydroxide was able to excrete up to about 750 cc. normal solution per animal per day taken with the feed without apparent ill effect, and the carbonate and sulfate were well tolerated up to a level of 1000 cc. per animal per day. There were no marked effects on the average rate of gain of any of the lots except when over 500 cc. were fed. There were no effects on the skeleton or other tissues of the acid-fed hog, which was slaughtered at the close of the experiment, which could with certainty be ascribed to the ration fed.
THE ACID-BASE BALANCE IN ANIMAL NUTRITION

III. The Effect of the Addition of Alkalies to the Ration on the Growth and Well-being of Swine. Further Data on Acid-feeding.

By ALVIN R. LAMB and JOHN M. EVVARD

The data reported in the earlier papers of this series\(^1\) show the remarkable tolerance of swine to strong acid ingested with the ration. The amounts of acid fed were so many times greater than could possibly occur as potential acidity in any satisfactory natural ration that the tendency, which is still somewhat current, to suggest the advisability of a balance between the acid- and base-forming mineral constituents of such a ration seems rather unnecessary, at least for swine.

Our conclusions, based on about ten months of acid feeding, during which growth and well-being were not interfered with, confirm the earlier conclusions of Steenbock, Nelson and Hart\(^2\), who carried on metabolism experiments with swine and calves, and Wells and Ewing\(^3\), who concluded that young pigs could neutralize and excrete without ill effect 4 cc. normal acid solution daily per kilogram live weight. Our metabolism studies, on rations of both high and low calcium content, while feeding 300 cc. of normal sulfuric acid solution daily to a 60 pound pig, showed from 60 percent to 75 percent of the ingested acid neutralized by means of ammonia, with a corresponding decrease in the urea excretion and no effect on the positive nitrogen balance. The efficiency of the protective mechanism does not wholly depend, however, upon the actual increase in ammonia salt excretion, but upon the prevention of the depletion of fixed bases in the body tissues. Only a long-time experiment will show whether or not there is a gradual depletion of these bases. Our experiments have been planned with this fact in mind.

It is of considerable importance in the continuation of fundamental studies of the role of mineral elements in the body, as well as in the extension of practical knowledge of mineral nutrition, to know definitely whether the minerals in a ration must be carefully balanced, or whether the effect of an excess of potential acid or alkali within reasonable limits may be disregarded. It is also of prime importance to determine whether the cereal rations commonly fed to swine and poultry

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should have their potential acidity corrected. In 1915 McColllum wrote:

Emphasis has been laid upon the balance between the base and acid-forming elements as a factor of importance in nutrition, but convincing experimental evidence is wholly lacking to demonstrate that diets acid within moderate limits produce physiological disturbances in normal individuals.

Nevertheless considerable importance is still attached to that single feature of the balance between these elements which affects the production of hydrogen ions in the animal body, disregarding the possible influence of the balance of these elements in their other physiological roles. Workers who have recently carried on extensive studies of the acid-base ratio of the mineral elements in army rations, in dairy cow rations, in poultry rations, etc., have disregarded abundant evidence showing the remarkable efficiency of the protective mechanism of the body in neutralizing acid by means of ammonia production and by excretion of acid phosphates. They have also disregarded long-time trials which have demonstrated the ability of swine, dairy cows, and rats to neutralize highly acid rations while continuing growth and reproduction.

Lyman states that the reason for the failure of his synthetic rations to maintain rabbits was their high protein and potential acidity, though the rations were lacking in vitamins and were very unappetizing. We have found the appetite and consumption factors in accustoming rabbits to purified rations to be very important. Unpublished work which is still in progress in this laboratory, has shown that rabbits, though more sensitive to acid than other species, will grow and reproduce normally when fed a ration which yields 3 to 4 cc. normal acid per rabbit per day, provided the ration is satisfactorily constituted, both in chemical and physical character. This amount of acid is near the limit that can be handled by the rabbit, as is easily demonstrable by increasing slightly the acid content of the rations. The well-known lack of ability of the rabbit to elaborate any appreciable quantity of ammonia for neutralization is sufficient explanation for its limited ability to take care of highly acid rations. McClendon and collaborators found that rabbits on a ration of oats and sprouting barley showed a markedly lower alkali reserve by the hydrogen electrode titration method than other rabbits on carrots and hay or cabbage rations. They failed to find, however, any decrease in

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alkali reserve in the blood of men or dogs when the normal diet was changed to one with sufficient potential acidity to greatly increase the acidity of the urine. The fact that some workers do find decreases in the alkali reserve by other methods does not, perhaps, signify without further proof that the normal animal whose plasma bicarbonate is reduced 10 percent from the average is on a correspondingly lower plane of well-being. This point is now being investigated.

While the lowering of the alkali reserve by means of acids superimposed upon a ration may be carried to the point of breaking down the mechanism of neutralization, the important fact demonstrated in these experiments, at least for swine, is that such acidity must be much higher than the natural potential acidity of any natural ration which is otherwise satisfactory, before growth, reproduction or well-being are interfered with. This was our main conclusion and was italicized in the paper just quoted.

In this connection, however, Forbes has taken issue with us on the basis of his earlier conclusions and of an experiment with two pigs which showed a slight decrease in plasma bicarbonate when calcium acid phosphate (precipitated bone phosphate) was added to a basal ration of cereals. While the statement is made that the decrease in alkali reserve is 15 percent, the authors are here comparing the figures obtained when calcium carbonate was added to the ration. The actual decrease from the plasma bicarbonate on their basal ration was from 68.4 to 64.4 in one case, and from 72.4 to 68.0 in the other case. The authors also state that the urinary acidity and ammonia vary in a manner concordant with the alkali reserve estimations, which they confirm. Their data, however, show less urinary ammonia in the acid-feeding periods than in the control periods. The authors then conclude that these variations in alkali reserve would probably result in unfavorable changes of body function, which prophesied result they do not demonstrate.

Forbes and his co-workers further state:

In this connection we are unable to follow Lamb and Evvard in some of the conclusions which they draw from their study of the acid-base balance in swine. Thus, contrary to their main conclusion, "On neither ration did the mineral acid cause a significant loss of calcium, nor did it interfere with the storage of protein," their data for Experiment 1 show, as a result of mineral acid ingestion, a decreased retention of calcium amounting to one-fourth or one-fifth according to whether it is computed with reference to the absolute amount or the proportion of the intake retained. It should also be noted that the results from Experiment 2 are conflicting since the first control period makes it appear that the mineral acid feeding had diminished the loss of calcium by 0.030 gm. of CaO per day, while the second or following con-

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trol period indicated, with opposite significance, that the acid feeding had increased the loss by 0.550 gm. of CaO per day. The authors averaged these contrary findings.

These criticisms, which challenge the conclusions drawn from our previous work, fail to take account of all factors which were discussed at that time. Sulfuric acid, which forms a very insoluble salt with calcium in the tract and would thus cause an experimental wastage of calcium in the feces, was fed at a level 1000 percent higher than the natural potential acidity of our corn, tankage and middlings ration, and 225 percent higher than the acidity of our second ration of corn and black albumin, a ration fairly high in protein, and containing almost no calcium. Even under such severe conditions the loss of calcium on the first ration, which was high in calcium, was not serious. The decreased retention of calcium oxide was 0.70 gms. per day on an intake of about 10 gms. CaO or one-fourteenth. The positive daily balance was 2.58 gms. CaO during this acid feeding period. In the second experiment, when the ration was so low in calcium that the animal was in negative balance before the acid was added to the ration, the animal did not use an appreciable amount of calcium to neutralize ingested acid, as the effect on the Ca balance was negligible in either direction, unless one is inclined to ascribe importance to variations within the experimental error. If the animal had been on the low calcium ration for some time, these variations in calcium balance would have been significant. Unfortunately this was not the condition as was noted at the time these data were published.

Our conclusions as to the effect of the acid on calcium retention are substantiated, however, by Givens and Mendel\(^1\)\(^2\)\(^3\)\(^4\). The effect on the nitrogen balance was more favorable than otherwise. These data are also substantiated by the growth and well-being of the acid-fed swine for ten months in our earlier experiment, followed by successful production of young, altho they were not successfully raised. In this connection, however, a similar experiment is being carried on at this time in which four sows have farrowed and raised 27 pigs after eight months of acid feeding. Five gilts from these litters are now continuing satisfactorily on the same high acid ration, their age at present being about six months. It is intended to continue this test thru one more complete generation to give opportunity for unfavorable effects to manifest themselves. In the experiments to be reported here, the feeding of sulfuric acid to one lot of two pigs has been repeated, and the results obtained will be compared below with the control animals and with the lots fed alkalies.


\(^{14}\)Givens, M. H., ibid., 35, 241, 1918.
Altho some natural food materials contain a much greater potential excess alkalinity than the highest potential acidity found in natural foods, the effect of such alkalinity in animal nutrition has not been studied nearly so extensively as has the effect of acids. Altho the latter question in the matter of the nutrition of normal animals has been confused in the past with such pathological manifestations as diabetic acidosis, the demonstrated efficiency of the protective mechanism of the normal animal body against acids seems to justify our conclusions, at least insofar as the natural potential acidity of foodstuffs is concerned. The question discussed here should not be complicated by that of alkali therapy in acidosis, where caution has been advised with respect to the amounts of alkali which can safely be used. It may be assumed that large amounts of alkali may be safely excreted as carbonates, but it would be well to know more definitely in the case of the normal animal, whether or not such an excretory burden would have any unfavorable effect on the animal when the alkali is fed under controlled conditions for a period of months during the growing period. The possibility of an alteration of the optimum concentration of salts in the intestinal tract and a consequent alteration of the capacity for the absorption of nutrients, or a possible increased permeability to toxins, are important considerations in all phases of the study of mineral nutrition. Such adverse effects can be satisfactorily ruled out only by observations on the growth and well-being of animals during a considerable period under well-controlled experimental conditions. Therefore we have compared the effect of alkalies added to the ration of swine during the growing period in the same manner as with the acids in our previous work.

Alkalies as such are not often given to animals, altho lye is sometimes fed to swine as a prophylactic against infestation with intestinal parasites and condimental mixtures often include carbonates. A toxic effect was attributed to alkali by Moore, who concluded that deaths among pigs fed on garbage were caused by free alkali in the powdered soap which found its way into the garbage as then fed. He reports that two or three ounces of the powdered soap daily caused death with intestinal lesions and other changes when fed to small pigs for a period of one to two weeks. The soaps analyzed contained about 50 percent of sodium carbonate, but unfortunately the other constituents were undetermined.

Larsen and Bailey, at the South Dakota Agricultural Experiment station, found that the natural "alkali water" of that

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region produced no ill effect whatever when given to dairy cows under well-controlled conditions. They state that one of the principal substances in the "alkali water" was sodium sulfate. Dietrich*, at the Minnesota Agricultural Experiment station, raised pigs successfully on a ration which included a small amount of lye. Many practical feeders use small amounts of lye in feeding pigs, but its effect has never been carefully studied.

Sodium sulfate, one of the salts fed in our work, has a marked effect in increasing the absorption of sodium chloride from the intestines, as shown by Goldschmidt and Dayton\(^{19}\). They reported that this effect increased with increasing concentrations of sodium sulfate. The stimulating effect of this salt on the water consumption in our work may possibly be referred to the effect observed by them, which is related to its cathartic effect.

**EXPERIMENTAL**

The experimental conditions were made as nearly as possible similar to those in the acid-feeding experiment reported in the first paper of this series. The ration used was the same, viz., 80 percent corn, 15 percent meat meal tankage, and 5 percent standard wheat middlings. The potential acidity of the mineral content of the ration was about 2.5 cc. normal acid solution per 100 grams of feed. The animals were fed twice daily, as before, under practical feeding conditions, so that no experimental factors would enter into the result save only the addition of the alkalies to the ration, which were added, as were the acids in our first experiment, in the form of normal solutions.

Fifteen pigs, about six months of age, and averaging 130 pounds each, were divided into five lots of equal number. Unfortunately we were not able to use as uniform a group of animals as in our acid-feeding experiment, but these pigs were in fairly good condition, altho they showed considerable variation in size. Their previous treatment had been identical.

Lot I was used as a control, Lot II received sulfuric acid, Lots III, IV and V received equivalent amounts of sodium hydroxide, sodium carbonate, and sodium sulfate respectively. During the first four periods all lots received equal amounts of feed, as regulated by the appetite of the least-eating lot. During Period 4 the consumption of the acid and alkali additions to the rations was 500 cc. normal solution per pig per day, as shown in table I. This is the amount of acid successfully taken by the animals in our earlier experiment.

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*\(^*\)Dietrich. Unpublished data.

### TABLE I—DAILY GAIN PER PIG, DAILY FEED CONSUMED PER PIG AND FEED PER 100 LBS. GAIN BY PERIODS.

<table>
<thead>
<tr>
<th>Period</th>
<th>Lots I (Control)</th>
<th>Lots II (H₂SO₄)</th>
<th>Lots III (NaOH)</th>
<th>Lots IV (Na₂CO₃)</th>
<th>Lots V (Na₃SO₃)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Days</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feb. 22-Apr. 3</td>
<td>40</td>
<td></td>
<td></td>
<td>Feb. 22-Oct. 20</td>
<td>240</td>
</tr>
<tr>
<td>Apr. 3-23</td>
<td>20</td>
<td>150</td>
<td>538</td>
<td>Apr. 23-July 22*</td>
<td>90</td>
</tr>
<tr>
<td>Apr. 23-May 23</td>
<td>20</td>
<td>400</td>
<td>715</td>
<td>Apr. 23-July 22*</td>
<td>90</td>
</tr>
<tr>
<td>May 23-June 22</td>
<td>30</td>
<td>500</td>
<td>715</td>
<td>Sept. 20-Oct. 20</td>
<td></td>
</tr>
<tr>
<td>June 22-July 22</td>
<td>30</td>
<td>715</td>
<td>715</td>
<td></td>
<td>240</td>
</tr>
<tr>
<td>July 22-Aug. 21</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td>**</td>
</tr>
<tr>
<td>Aug. 21-Sept. 20</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td>538</td>
</tr>
<tr>
<td>Sept. 20-Oct. 20</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td>**</td>
</tr>
<tr>
<td>Apr. 23-July 22*</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
<td>**</td>
</tr>
<tr>
<td>Feb. 22-Oct. 20</td>
<td>240</td>
<td></td>
<td></td>
<td></td>
<td>**</td>
</tr>
</tbody>
</table>

### REMARKS

*June 22 to July 22—Lot II did not receive or eat much feed as others. Lots I, III, IV and V were all fed the same April 23 to July 22.

Average daily gain figures for all lots are comparable during February 22-June 23. All lots except II are comparable during February 22-August 21. After this date each lot full-fed according to appetite.

**Of no particular significance.
All lots were thrifty at this time, consuming in Period 4, 7.83 pounds of feed per pig per day, averaging 260 pounds live weight, and gaining 1.33 to 1.53 pounds per day.

During the next period (Period 5) an attempt was made to determine the upper limit at which the acid and alkalies could be fed. At the beginning of this period the amount given was doubled, or raised to 1000 cc. normal solution per animal per day. Within a few days the acid-fed lot (Lot II) "went off feed," eating very little. When they failed to improve at the middle of the period, the amount of acid and alkali added to the rations was reduced to 500 cc. and gradually increased again to 1000 cc. When this point was reached, however, Lot II again refused the greater part of the feed, and would often regurgitate what was eaten. This and other symptoms showed that irritation of the stomach by the large amount of strong acid was a considerable factor, but the amount fed was unquestionably beyond their capacity for neutralization and excretion. During the last seven days of Period 5, Lots I, III, IV and V were allowed their usual amount of feed plus 800 cc. of their respective alkalies, while Lot II was fed the ration without acid and allowed to recover. Until this time the other lots had been allowed only the amount of feed which Lot II would eat, which fact accounts for the low daily gains for this period shown in table I.

Until the acid was increased over 500 cc. per day, Lot II was in thrifty condition and gaining well, as shown in tables I and II, as in our earlier experiment, when a similar amount of acid was fed for a much longer period. It seems from these observations, however, that 500 cc. per day was near the limit. Judging by the performance and appetite of Lot III during Periods 5 and 7, the upper limit of amount of sodium hydroxide solution which they could handle was about 750 cc., while Lots IV and V apparently were able to consume 1000 cc. of the respective additions to their rations without ill effect.

During Periods 5 and 6, all lots except Lot II received equal amounts of feed, so that the growth figures in table I are comparable for all lots in Periods 1 to 4 inclusive, and for Lots I, III, IV and V in Periods 1 to 6. After that time, each lot was allowed as much feed as it would eat, and appetite as well as other factors have a bearing therefore upon the growth in the last two periods.

It should be noted at this point that the data in tables I and II are based on the performance of three pigs in each lot for the first 70 days. The poorest gaining pig was then taken out of each lot, and the data for the balance of the experiment are based upon the performance of two pigs in each lot, except in Lot II after the end of Period 5. At that time one sow in Lot
II died of torsion and rupture of the large intestine. While this is considered purely accidental, the radical acid feeding may have been a contributing factor. During the last three periods the figures on Lot II are therefore based on the performance of one pig. The growth figures on this animal show the effect on appetite of the severe acid feeding in Period 5. At the end of the experiment, however, when this animal was slaughtered at a weight of 400 pounds it was in better condition than the control animal from Lot I.

The economy of growth, as shown by the feed requirement per 100 pounds gain in table I shows definitely that in Periods 1 to 4 the acid feeding did not increase the feed requirement of Lot II, until the amount fed was raised above the limit of neutralization and excretion. The economy of growth of the other lots can best be compared by means of the average figures given in table I for the 90 day period from April 23 to July 22, when all lots except Lot II were receiving the same amounts of feed. It will be noted that there is no great difference in feed requirement among these lots for that period. Other comparisons may be made in table I if the disturbing conditions of Periods 5 and 6 and the varying feed intakes in Periods 7 and 8 are kept in mind.

Further interesting comparisons in the rate of gain in the first four periods are shown in table II. In this table Lot IV appears in the most unfavorable light. It must be remembered, however, in the inspection of this table, that some of the dif-

<table>
<thead>
<tr>
<th>TABLE II—AVERAGE DAILY GAIN PER PIG AND PERCENT INCREASE IN DAILY GAIN OVER PRELIMINARY PERIOD, DURING TIME WHEN ALL RECEIVED SAME AMOUNT OF FEED*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>Feb. 22-Apr. 8—40 days</td>
</tr>
<tr>
<td>Control period</td>
</tr>
<tr>
<td>Apr. 8-23—20 days</td>
</tr>
<tr>
<td>150 cc. acid or alkali per day</td>
</tr>
<tr>
<td>Apr. 23-May 23—30 days</td>
</tr>
<tr>
<td>400 cc. acid or alkali per day</td>
</tr>
<tr>
<td>May 23-June 22—30 days</td>
</tr>
<tr>
<td>500 cc. acid or alkali per day</td>
</tr>
<tr>
<td>June 22-July 22—30 days</td>
</tr>
<tr>
<td>Daily average of 715 cc. alkali to Lots III, IV, V</td>
</tr>
<tr>
<td>Feed restricted</td>
</tr>
</tbody>
</table>

*During the first 70 days the average daily gain is the average of 3 pigs; after that time it is the average of 2 pigs.
†These animals refused feed because acid was raised to 1000 cc.
ferences may be due to individuality, which is a stronger factor in these experimental animals than in the litter-mates we used in our first acid feeding experiment. The marked increase in the rate of gain of Lot V over the other lots in Periods 3 and 4 may possibly be correlated with the increased water consumption of this lot shown in Table III. As noted above, the lots receiving carbonate and sulfate tolerated a larger amount of these salts than did Lot III of the fixed alkali. In this connection it may be worthy of note that we have fed a rabbit on a ration of grain and hay plus an average of 25 cc. normal sodium hydroxide solution per day for 60 days, followed by another 60 days at 50 cc. normal solution per day. This animal remained in good condition and continued to grow during this time, and until the experiment was discontinued.

The effect of these alkalies and salts on appetite may be noted in Periods 7 and 8, when each lot was fed all it would readily consume. In Period 7, the acid and alkali fed to Lots II and III depressed their feed intake markedly but not the economy of growth on the feed taken. Lots IV and V showed no marked effect on appetite except that they consumed more feed and less water after the salts were removed from the ration. The greatest and most economical gains were made in Lot V during Period 7. Of course this cannot with certainty be ascribed to the sodium sulfate. Indeed the amounts of these additions to the rations were excessive, but the results will be of value in our study of condimental salt mixtures for swine.

**SLAUGHTER TEST ON ACID-FED HOGS**

One animal from Lot I and the remaining animal in Lot II were slaughtered six weeks after the conclusion of the experiment. The acid was fed up to the time the hogs were slaughtered. The intestinal contents of the acid-fed hog were found

### TABLE III—TOTAL WATER CONSUMPTION PER PIG PER DAY DURING 10 DAY PERIODS AT REGULAR INTERVALS DURING EXPERIMENT. (IN FEED AND IN DRINKING TRough).

<table>
<thead>
<tr>
<th>Dates</th>
<th>Lot I lbs.</th>
<th>Lot II lbs.</th>
<th>Lot III lbs.</th>
<th>Lot IV lbs.</th>
<th>Lot V lbs.</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 13-23</td>
<td>17.8</td>
<td>23.3</td>
<td>19.0</td>
<td>18.3</td>
<td>21.0</td>
<td>All lots fed same amount of feed.</td>
</tr>
<tr>
<td>May 13-23</td>
<td>22.5</td>
<td>29.5</td>
<td>23.5</td>
<td>28.0</td>
<td>28.0</td>
<td>All lots fed same amount of feed.</td>
</tr>
<tr>
<td>June 12-22</td>
<td>24.5</td>
<td>30.5</td>
<td>22.5</td>
<td>23.0</td>
<td>31.0</td>
<td>All lots fed same amount of feed.</td>
</tr>
<tr>
<td>July 12-22</td>
<td>17.5</td>
<td>13.0</td>
<td>17.0</td>
<td>24.0</td>
<td>23.5</td>
<td>Feed restricted in amount.</td>
</tr>
<tr>
<td>Aug. 11-21</td>
<td>14.7</td>
<td>26.0</td>
<td>15.3</td>
<td>21.7</td>
<td>20.5</td>
<td>No acid to Lot II.</td>
</tr>
<tr>
<td>Sept. 10-20</td>
<td>16.7</td>
<td>22.5</td>
<td>16.0</td>
<td>24.0</td>
<td>24.0</td>
<td>Control period. All received same amount of feed.</td>
</tr>
<tr>
<td>Oct. 10-20</td>
<td>16.5</td>
<td>17.7</td>
<td>12.7</td>
<td>17.4</td>
<td>18.4</td>
<td>All fed according to appetite.</td>
</tr>
</tbody>
</table>

Note: No salt (NaCl) fed except that contained in the ration.

*Acknowledgment is gratefully made of the cooperation of Mr. C. C. Culbertson and Prof. M. D. Helser in carrying out these slaughter tests.
to be acid throughout both intestines. The membranes of the tract were slightly lighter in color than in the control. The internal organs were apparently normal. The bones of the acid-fed hog were found to be harder than the control, accompanied by a greater ossification of cartilaginous tissue. There was also less marrow in the leg bones of the former. This condition, however, may have been due to individuality, as we found no such differences in the bones of animals slaughtered from a later experiment.

Goto\(^{20}\) of the Rockefeller Institute for Medical Research, has reported marked changes in the composition of bones and

\[\text{Fig. 1. Cross sections of radius and ulna, metacarpals, and ribs. Control on left, acid-fed on right. Anterior view. (The radius and ulna are not cut at exactly the same level.)}\]

Fig. 2. Bones shown in fig. 1 with marrow removed. Control on left

muscle tissue of rabbits which were fed bread and cabbage plus 25 to 75 cc. of 0.25 N hydrochloric acid daily by stomach tube for one to four weeks. He reports a great reduction in the fat content of the bones and a loss of mineral constituents of the muscle tissue. His rabbits, however, did not consume nearly enough feed to maintain their weight, and these losses, particularly of fat, may therefore be due to partial starvation.

The bones of our last acid-fed swine have not been completely analyzed, but they show no such loss in fat content. We have been feeding acid rations to rabbits for long periods and are now investigating these points, as well as the effect of prolonged acid feeding upon mineral metabolism.

Figs. 1 to 4 show bones of the hogs slaughtered in the present experiment. The observed differences in the size of the marrow cavities may readily be seen in fig. 1. Smaller sinuses in the head of the control hog may be noted in figs. 3 and 4.
Fig. 3. Cross section thru head, frontal sinuses and olfactory fossae. Control on left. Posterior view.
Fig. 4. Cross section thru head showing posterior part of nasal cavity and anterior part of frontal sinuses. Control on left. Anterior view.