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THE EFFECT OF RATIONS ON THE PRODUCTION OF URINARY CALCULI IN SHEEP

I. E. NEWSOM, J. W. TOBISKA, and H. B. OSLAND

COLORADO AGRICULTURAL EXPERIMENT STATION
COLORADO STATE COLLEGE
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Fort Collins, Colorado

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The Effect of Rations on the Production of Urinary Calculi in Sheep

I. E. Newsom, J. W. Tobiska, and H. B. Osland[1]

Since 1923 those connected with the Colorado Agricultural Experiment Station have had frequent opportunity to observe urinary calculi in sheep. These observations have dealt with feeder lambs, mostly because northern Colorado, in which the Experiment Station is located, is a lamb-feeding area. However, it is known that the disease is also prevalent in range and breeding animals.

The disease occurs only in males and is much more prevalent in the fall and winter than in the summer. This latter statement must be modified by stating that lamb feeding is essentially a winter occupation. In any event the malady has not been seen in lambs on green pasture. Experience seems to indicate that the disease is more frequent in drought years than in those with heavier rainfall. It is also more prevalent when cane hay and corn fodder are used as roughage. While the disease does occur when the lambs are getting alfalfa, it may be said that it is not as common when a plentiful supply of that forage is available. Losses in some feedlots have run to 5 percent during a single season.

Review of Literature

In 1937 (*12*)[2] the senior author discussed urinary calculi and reviewed the literature in a paper read before the American Veterinary Medical Association. The following factors were considered: Water, vitamin A deficiency, mineral imbalance, reaction, hyperparathyroidism, infection, and urinary irritation. This review will be confined to the work with sheep. Briefly it may be said that in 1910 the Iowa station (*10*) carried out extensive trials with rams which seemed to indicate that sugar beets and mangels predisposed to the condition. Later, in 1923 (*6*), the same station cast suspicion on both cane and beet molasses.

The Indiana station in 1931 (*13*), after several trials, failed to produce calculi but observed that root crops greatly increased the

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[1]Newsom, veterinary pathologist; Tobiska, chemist; Osland, formerly animal husbandman; Colorado Agricultural Experiment Station. Credit is due the following men who have taken part in the work herein reported: C. E. Vail and Earl Douglass, Chemistry Section, and William Newcomb, formerly of that section; Frank Thorp, Jr., formerly of the Pathology and Bacteriology Section, and G. S. Harshfield and Hilton A. Smith of that section; and Ivan Watson, formerly of the Animal Investigations Section.

[2]Italic numbers in parentheses refer to references cited, page 41.

flow of urine and thus decreased the likelihood of calculi formation. They incriminated cereal grains and particularly bran. Quoting from their report: "When wheat bran is introduced into a ration it carries with it a large mineral content, especially phosphorus compounds. These readily form water-insoluble combinations with calcium, magnesium, and aluminum, and gravel is deposited in the kidney and bladder, thereby often causing serious trouble to male sheep."

The Ohio station in 1935 (*4*) observed that "lambs fed a ration low in calcium and high in phosphorus showed a marked tendency to develop urinary calculi."

In 1937 (*16*) Shaw of Oregon reported that of six wethers on a vitamin A deficient diet, in connection with a lungworm experiment, all developed calculi. The stones were found to consist largely of silicates.

Eveleth and Millen in 1939 (*5*) reported the finding of high magnesium (6.5 and 5.6 mgm. percent) in the blood of two lambs with bladders ruptured from urinary calculi and offered the suggestion that some significance might attach thereto in view of the previous finding of Watchorn (*17*) with rats.

The Minnesota station in 1940 (*9*) took lambs from a flock showing calculi and kept them on high magnesium rations for 154 days, doubling the magnesium content of the blood but failing to produce urinary stones.

Schmidt in 1941 (*14*) reports that urolithiasis was a frequent complication in the study of vitamin A deficiency in cattle, sheep, and goats in Texas. These animals were on a basic ration of cottonseed hulls, kaffir, and cottonseed meal. It is interesting to note that some of the goats developed calculi when as much as 3,500 micrograms of carotene was added daily.

The Nebraska station during three lamb-feeding seasons, 1939-40 (*1*), 1941-42 (*8*), and 1942-43 (*2*), has experienced calculi. During the first of these seasons 42 and 58 percent respectively of the wethers on sorghum grain, cottonseed cake, bonemeal, and Atlas silage (cane) died from calculi in contrast with those lots receiving yellow corn and alfalfa. During the second season, of 27 wethers in the lot receiving shelled yellow corn, cottonseed meal, bonemeal, and beet-top silage, 21 developed stones. In the 1942-43 season lambs in the lot on shelled yellow corn, cottonseed meal, and beet-top silage reacted similarly, more than two-thirds of the lambs coming down with the disease. In the lot getting the same ration, except that barley replaced corn, the results were approximately the same except that the lambs were a little slower in coming down. A commercial product containing carotene in vegetable oil did not prevent the development of the disease.

The Idaho station in 1943 (*3*), after two series of feeding trials designed to test the relationship of vitamin A, calcium, phosphorus, and magnesium to urinary calculi, in which one clinical case developed, concluded that vitamin A deficiency had been eliminated under the conditions observed. These workers reported that silica composed more than 70 percent of the four calculi examined.

Feeding Experiments

Beginning in 1938 this Station, through the cooperation of its Animal Investigations, Chemistry, and Veterinary Pathology Sections, has carried on studies with sheep to throw more light on the problem of urinary calculi.

1938-39 Trial

Since suspicion had been thrown upon water consumption, vitamin A deficiency. wheat bran, beet tops, and beet molasses, the first feeding trial was set up to explore these factors. Seven lots of 96 wether lambs each were given the rations shown in table 1. The lambs were fed for 120 days beginning on November 15, 1938, and ending March 15, 1939. Two hundred thirty-eight lambs were shipped on March 21, 231 on April 11, and the balance on May 21. After March 21 the remaining lambs were put on yellow corn and alfalfa.

Forage and ash analyses of the various feeds were made, and 10 of the lambs in each lot were bled at the beginning and at the end of the experiment to determine any change in mineral constituents of the blood. Seven lambs in each lot were selected for urine determinations. These were placed on a raised platform and all urine was collected for a 3-day period. Each lamb was fitted with a harness that held a rubber funnel under the end of the prepuce, from which a tube was carried to a glass jar under the platform. This scheme worked exceptionally well and prevented the contamination of urine with feces. The jars were emptied daily. Since each of the seven lambs in each lot were on the rack for 3 days at a time, each individual came on every 21 days. Thus all seven of the lambs in each lot appeared on the rack five times and five of them appeared six times.

All animals were weighed weekly and the usual data showing gains and feed costs determined, but since that information is of only incidental value in the study of calculi it is not presented here. It may be obtained by writing to the Animal Investigations Section. It may be added, however, that the standard ration of corn and alfalfa always produced better gains than any of those on which calculi were produced.

TABLE 1.—*Number of lambs developing urinary calculi on different rations, 1938-39 feeding period, 120 days.**

Lot No. (96 lambs per lot)	Ration	Average pounds per day	Deaths from calculi	Died
1	Alfalfa Yellow corn "C" molasses Salt Water	1.84 .76 .14 .004 4.24	0	
2	Alfalfa Yellow corn Salt Water	1.98 .76 .005 3.84	0	
3	Alfalfa Yellow corn Bran Salt Water	1.85 .76 .14 .006 3.76	0	
4	Beet tops Yellow corn "C" molasses Oat straw Salt Water	2.62 .76 .14 .05 .004 3.92	0	
5	Cane fodder Yellow corn Bran Salt Water	1.87 .47 .09 .011 2.56	1	55th day
6	Cane fodder White corn Bran Salt Water	1.93 .48 .09 .011 2.27	5	93rd day 136th day 136th day 141st day 148th day
7	Cane fodder Yellow corn "C" molasses Salt Water	1.99 .48 .09 .009 3.20	0	

*These rations were maintained for 126 days, following which all lots were fed corn and alfalfa.

Results

It will be noted in table 1 that by the end of the regular 120-day feeding period only two lambs had died of calculi, one of these in lot 5 (cane fodder, yellow corn, and bran) and one in lot 6 (cane fodder, white corn, and bran). Out of the remaining lambs, however, four more were killed in a moribund condition from calculi after being placed on corn and alfalfa. All of these were from lot 6 (see fig. 1). Unfortunately no examination was made of the lambs that went

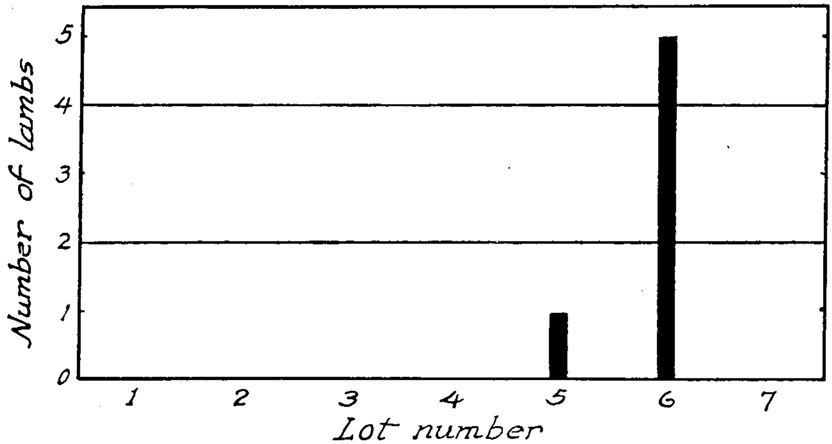

Figure 1.—Number of lambs developing urinary calculi, 1938-39.

to slaughter. No calculi developed in the lots receiving alfalfa, beet tops, or beet molasses.

Mineral Intake

Charts are presented (fig. 2) showing the intake in grams per day per lamb for the various lots in terms of P_2O_5, CaO, SiO_2, MgO, and the Ca-P ratio. Phosphorus was highest in lot 4 (beet tops), which showed no calculi. There was practically no difference in the other lots.

Calcium was also highest in lot 4, but lots 1, 2, and 3 (alfalfa) were appreciably higher in this element than lots 5, 6, and 7 (cane fodder).

Silica was low in the first three, notably high in lot 4 (beet tops), and moderately high in the last three.

Magnesium was highest in lot 4 but consistently lower in the last three than in the first three.

The Ca-P ratio was higher in the first four than in the last three.

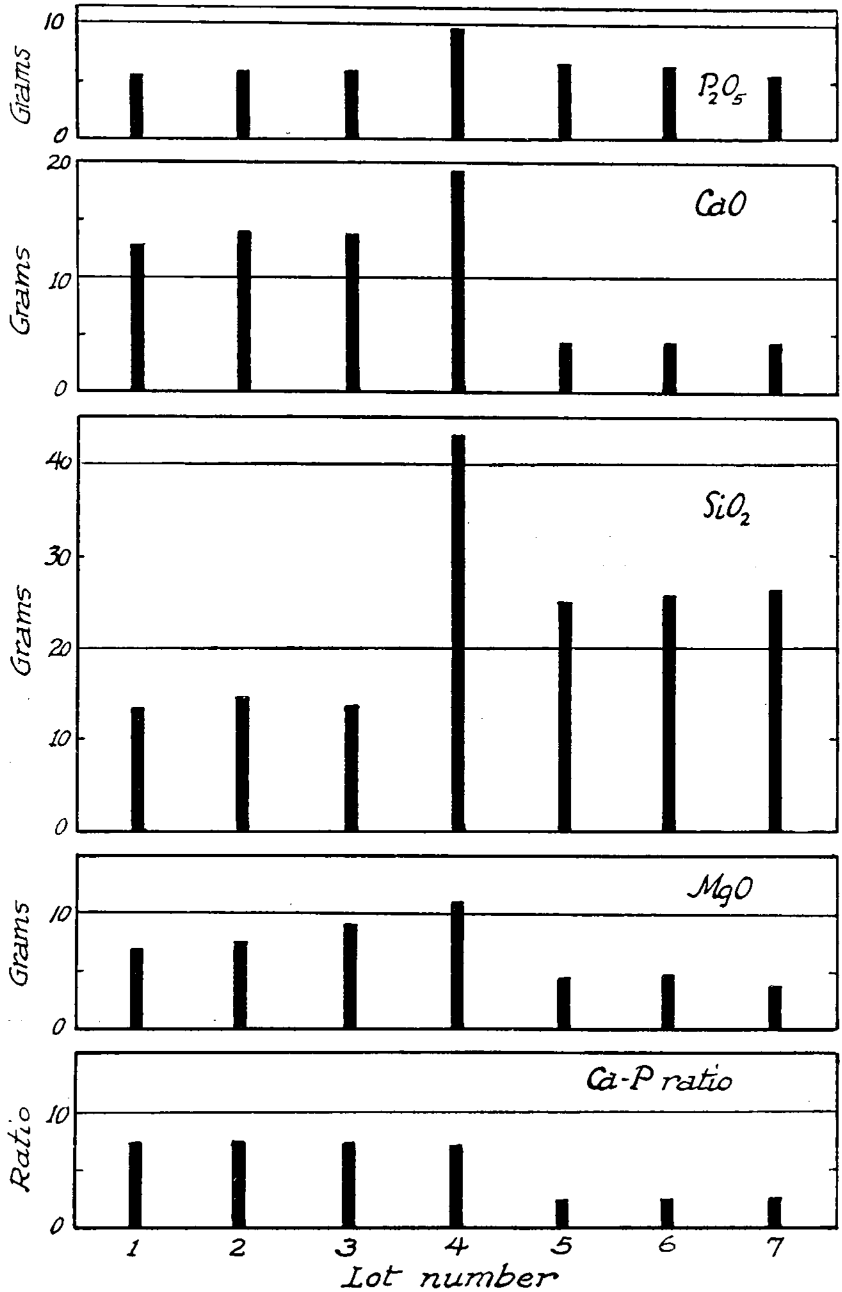

Figure 2.—Intake of minerals and calcium-phosphorus ratio, 1938-39 (per lamb per day by lots).

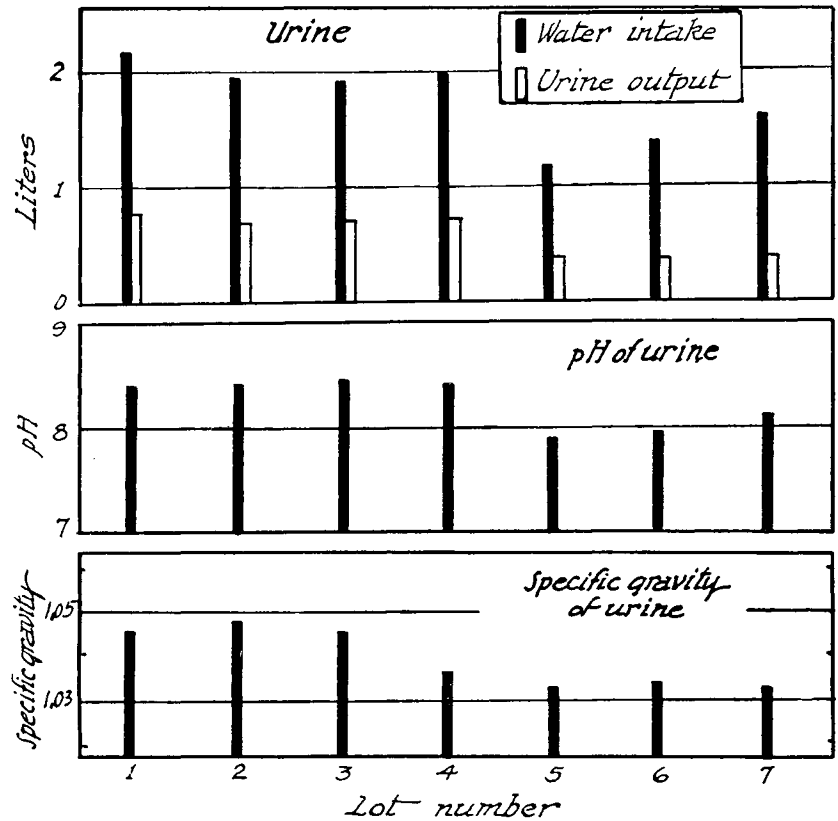

Figure 3.—Water intake and urine output in liters per lamb per day, pH of urine, and specific gravity of urine, 1938-39.

Urine

The graph (fig.3) compares the water intake and the urine output in liters per day. It is apparent that the lambs on alfalfa and beet tops consumed much more water and excreted more urine than those on cane fodder.

The average pH of the urine is consistently higher in the four lots on alfalfa and beet tops than in the three on cane fodder (fig. 3). The specific gravity was somewhat higher in the lots getting alfalfa, and intermediate in those on beet tops (fig. 3).

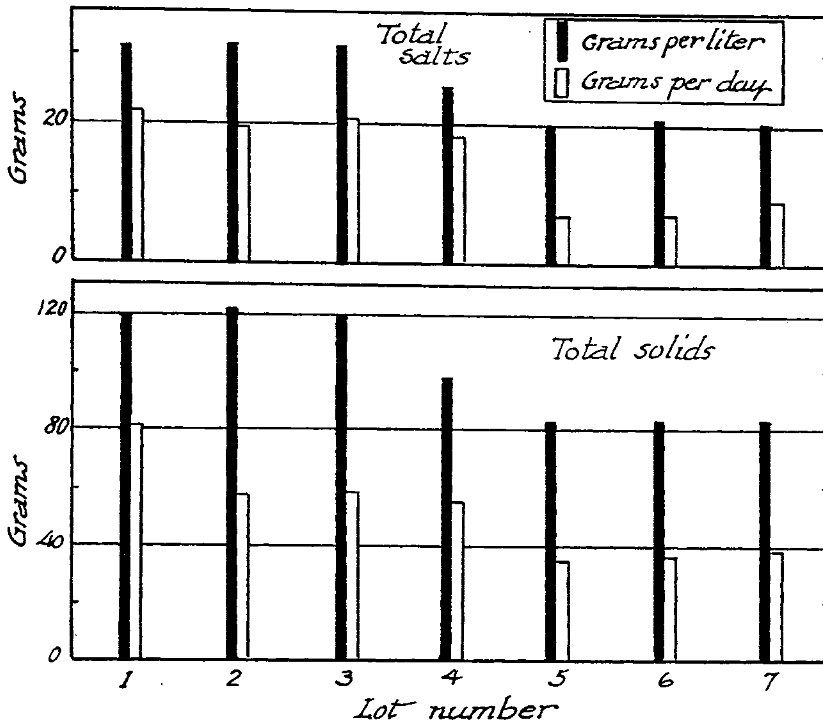

Figure 4.—Total salts and total solids in the urine in grams per liter and grams per day, 1938-39 (average per lamb by lots).

The total salts and total solids (fig. 4) were high in those fed alfalfa, intermediate in those on beet tops, and low in those on cane fodder.

There was less chlorine excreted per day (fig. 5) and more in grams per liter in those showing calculi (lots 5 and 6) than in the others.

The excretion of sulfur was much greater in the alfalfa lots, as might be expected.

The variations in phosphorus were insignificant.

There was a greater concentration of magnesium in the last three lots but this was due to the lessened flow of urine since there was no greater amount excreted per day.

Potassium was higher in the alfalfa lots and intermediate in the one getting beet tops.

Sodium showed a marked increase in the beet-top lot.

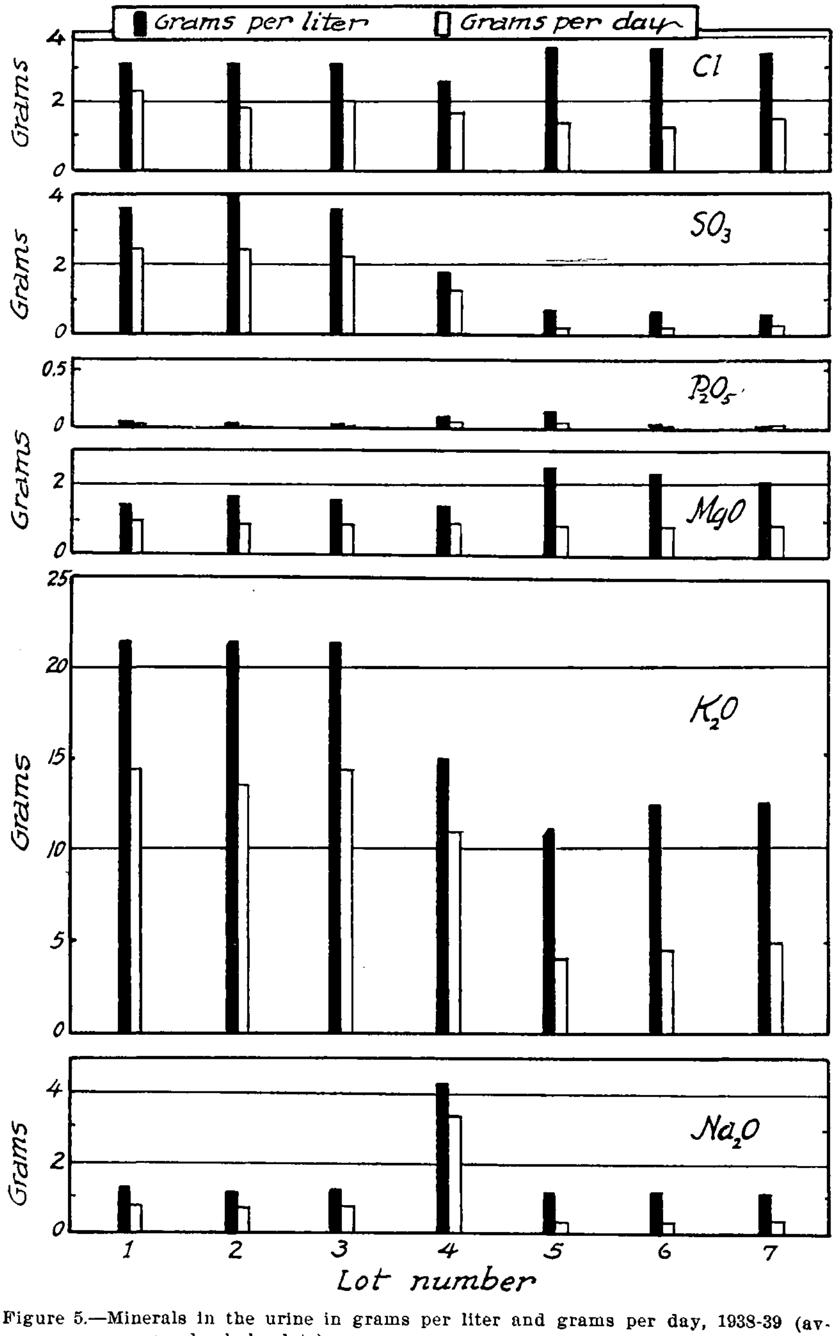

Figure 5.—Minerals in the urine in grams per liter and grams per day, 1938-39 (average per lamb by lots).

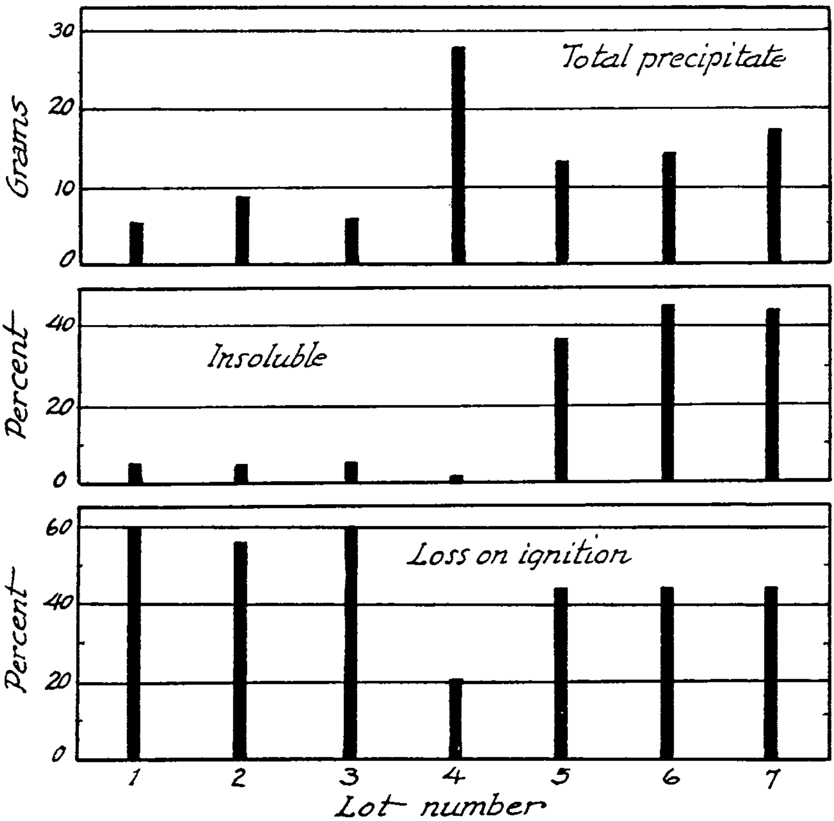

Figure 6.—Total precipitate in the urine, insoluble percentage, and percentage of loss on ignition, 1938-39.

Precipitates

After about 40 days it was noticed that several of the 3-day urine specimens showed considerable amounts of precipitate on standing in the refrigerator. These sediments were saved from all lots during the last 60 days, filtered, dried, and analyzed. Graphs (figs. 6 and 7) are shown which reveal the significant data.

The total amounts were highest in the beet-top lot (No. 4) and lower in the alfalfa lots than in those receiving cane fodder.

The insolubility was markedly higher in the cane-fodder lots and lowest on beet tops.

The CO_2 content roughly paralleled the solubility.

The content of organic matter was lowest in the beet-top lot and highest on alfalfa.

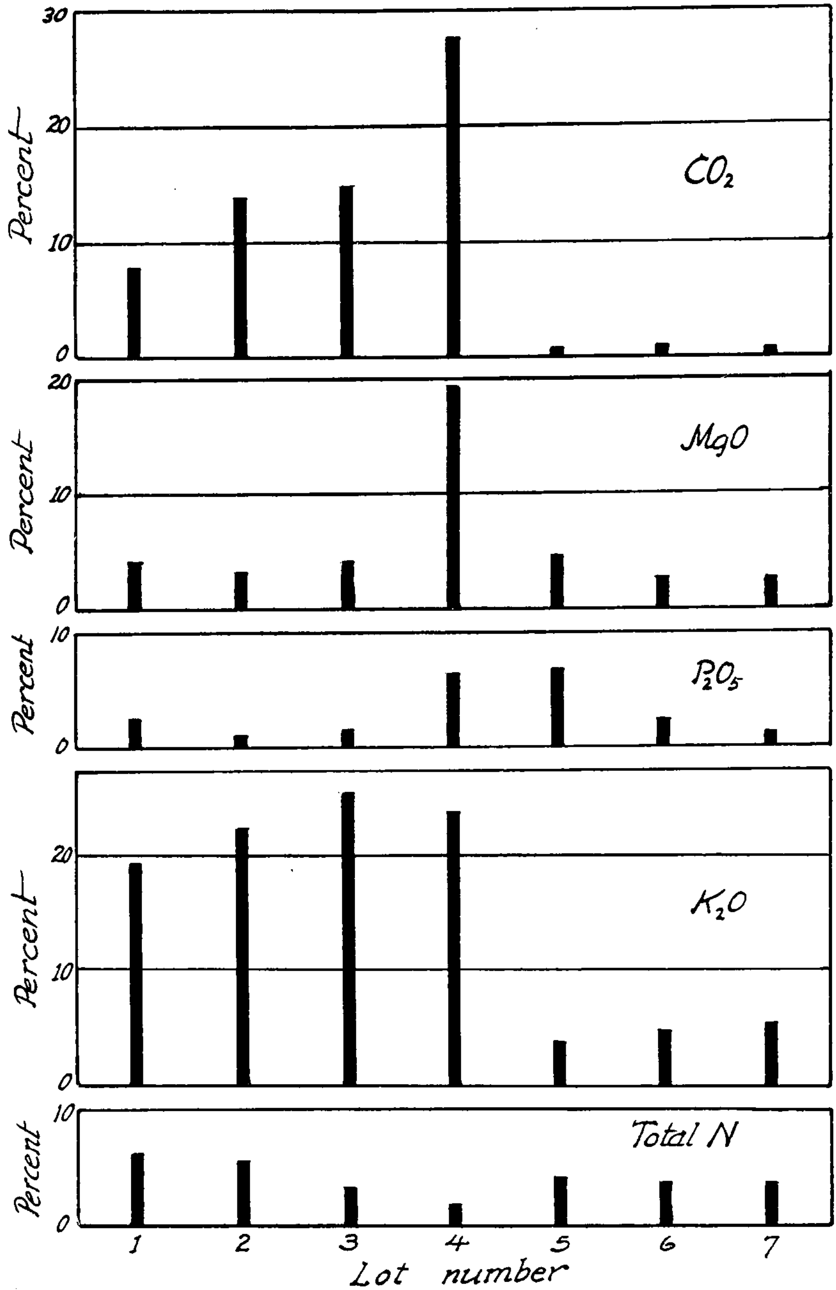

Figure 7.—Percentage of various minerals in the precipitate, 1938-39.

The magnesium was highest in the beet-top lot and approximately the same in the others.

The phosphorus was slightly higher in lots 4 and 5.

Potassium was significantly higher in the first four (alfalfa and beet tops) than in the last three (cane fodder).

No significance attaches to the difference in the total nitrogen.

Blood

Ten lambs from each lot were bled at the beginning and at the end of the experiment and the blood examined for calcium, phosphorus, and magnesium. The graphs (fig. 8) show a gain in blood calcium in lots 3, 4, and 5, reaching the peak in lot 6, one of the cane fodder lots in which the greatest number of calculi occurred. Lot 6 showed a decrease in phosphorus, whereas lots 3, 4, and 5 showed slight increases. Magnesium was consistently high at the end of the experiment in the three lots on cane fodder.

Summary of the 1938-39 Trials

Seven lots of 96 lambs each were fed for 120 days on rations designed to test the relationship of water consumption, beet molasses, beet tops, bran, and vitamin A deficiency to urinary calculi. Six lambs died of calculi, one in lot 5 (cane fodder, yellow corn, and bran), and five in lot 6 (cane fodder, white corn, and bran). Four of the latter group, however, died after having been changed to alfalfa and yellow corn.

The alfalfa and beet-top lots drank much more water and passed more urine than those on cane fodder.

The pH, specific gravity, and total solids were higher on alfalfa and beet tops.

There was a greater concentration of magnesium in the lots on cane fodder than in the other lots.

The insolubility of precipitates formed on standing was highest in the cane-fodder lots.

Two out of three of those lots on cane fodder showed calculi.

The indication from this trial was that alfalfa and beet tops were protective and that cane fodder, bran, and white corn (vitamin A deficiency? low water consumption?) were suspect. No suspicion was brought on beet tops or beet molasses.

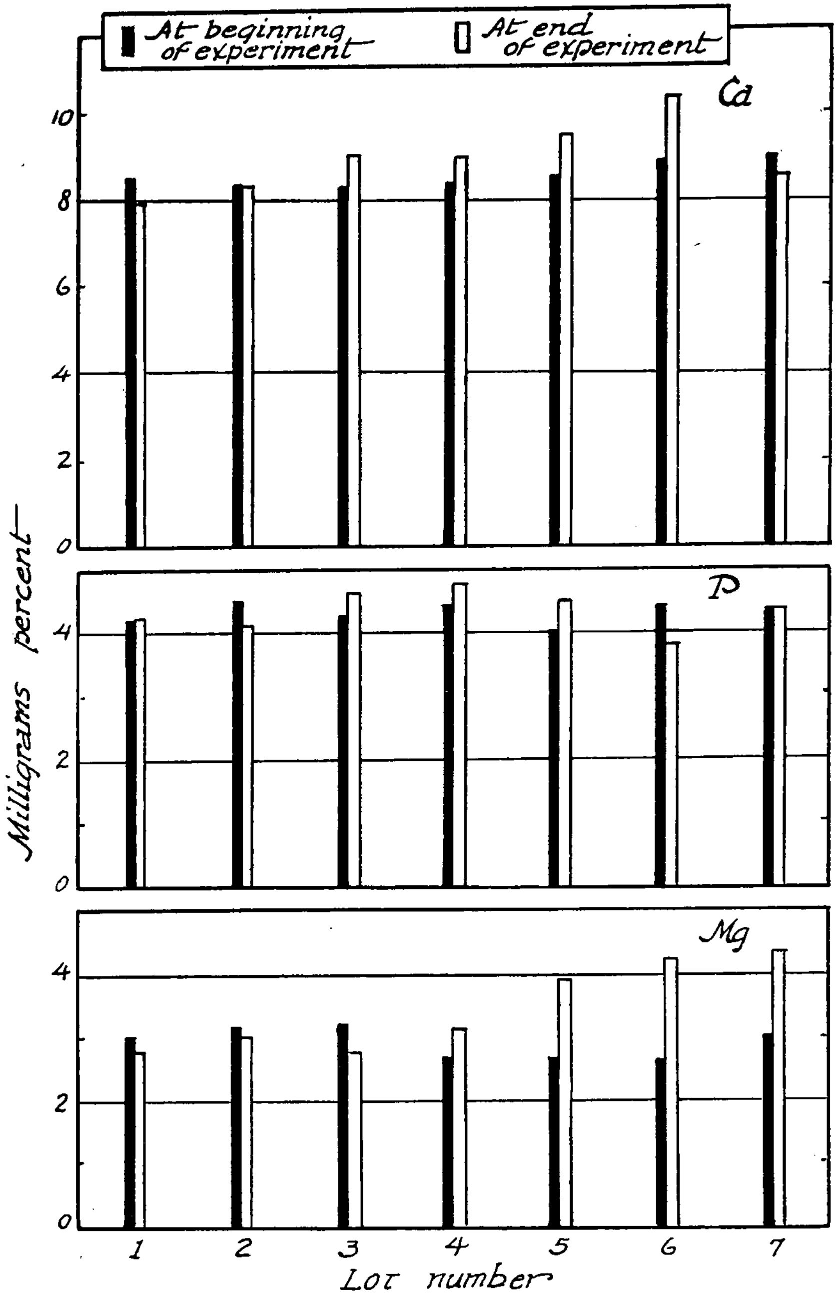

Figure 8.—Calcium, phosphorus, and magnesium in the blood at the beginning and at the end of the 1938-39 experiment (average per lamb by lots).

1939-40 Trial

The previous work having pointed to certain rations as potent factors in the production of calculi, the 1939-40 trial was set up to compare various grains, bonemeal, lime, and molasses.

Table 2 sets out the essential data on rations, days fed, and development of calculi. Only two animals developed clinical cases of calculi, these being in the lot on milo grain, bran, and cane fodder. The other stones were determined on slaughter. It will be noted that

TABLE 2.—*Number of lambs developing urinary calculi on different rations, 1939-40.*

Lot No. (25 lambs per lot)	Ration	Average pounds per day	Days fed	Deaths from calculi	Calculi at slaughter
1	Yellow corn Alfalfa Water	1.02 2.42 5.52	125	0	0
2	Barley Alfalfa Water	1.03 2.87 5.76	125	0	0
3	Wheat Alfalfa Water	1.02 2.52 5.68	125	0	0
4	Milo Alfalfa Water	1.02 3.53 5.84	125	0	0
5	Hay Millet Alfalfa Water	1.02 3.45 6.16	125	0	0
6	White corn Bran Cane fodder Water	.61 .18 2.56 4.64	140	0	1
7	Barley Bran Cane fodder Water	.61 .18 2.11 4.08	140	0	1
8	Wheat Bran Cane fodder Water	.61 .18 2.25 4.56	140	0	0
9	Milo Bran Cane fodder Water	.61 .18 2.52 4.32	140	2 (49th day (132nd day	1
10	Hay millet Bran Cane fodder Water	.61 .18 2.97 5.52	140	0	1

TABLE 2.—*Continued.*

Lot No. (25 lambs per lot)	Ration	Average pounds per day	Days fed	Deaths from calculi	Calculi at slaughter
11	White corn Bran Cane fodder Bonemeal self-fed Water	.61 .18 2.31 .00 4.16	140	0	0
12	White corn Bran Cane fodder Bonemeal Water	.61 .18 2.23 .004 4.32	140	0	0
13	White corn Bran Cane fodder Bonemeal Water	.61 .18 2.05 .013 3.92	140	0	2
14	White corn Bran Cane fodder Lime self-fed Water	.61 .18 2.11 .0003 4.40	140	0	0
15	White corn Bran Cane fodder Lime Water	.61 .18 2.01 .0044 4.08	140	0	0
16	White corn Bran Cane fodder Lime Water	.61 .18 2.68 .013 4.24	140	0	0
17	White corn "C" molasses Beet tops Water	.69 .27 4.24 7.44	125	0	0
18	White corn Bran Cane fodder Cane molasses Water	.35 .18 2.36 .27 5.12	140	0	2
19	White corn Bran Cane fodder Corn molasses Water	.35 .18 2.48 .27 4.48	140	0	2
20	White corn Bran Cane fodder "C" molasses Water	.35 .18 3.13 .27 5.92	140	0	0

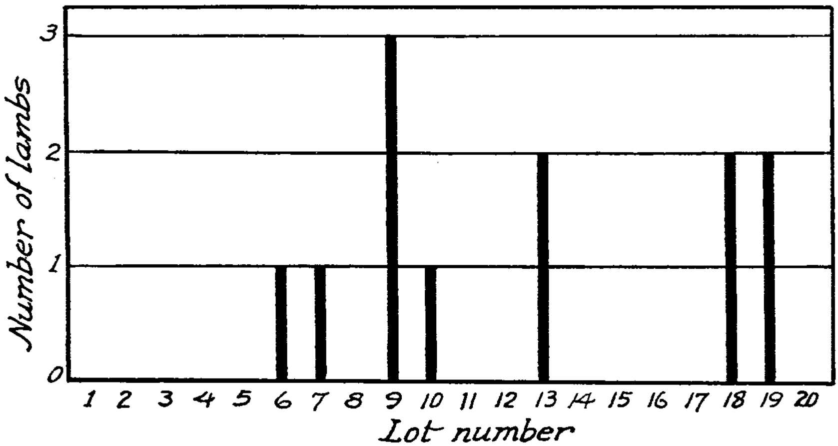

Figure 9.—Number of lambs developing urinary calculi, 1939-40.

they were scattered through the lots except that no animal getting alfalfa hay showed the disease, nor did any in the lot getting beet tops show calculi.

When bonemeal and lime were self-fed the lambs ate so little that it was inconsequential. It can hardly be said that the intended high-level feeding of these minerals was considerable, but there were two cases of calculi in the lot getting the largest amount of bonemeal. No animal getting lime showed calculi. Gravels were present in the lots receiving cane and corn molasses but were absent in those on "C" molasses (beets).

Graphs are presented showing the important data such as number of calculi (fig. 9) and mineral content of the rations (fig. 10).

No significant variations were noted in the phosphorus content of the rations. The lot getting the largest amount was No. 17 (beet tops) that showed no calculi.

Calcium was high in the alfalfa and beet-top lots, as might be expected, but there were no stones.

Magnesium was exceptionally high in the beet-top lot, but again there were no calculi.

Silica was low in the alfalfa lots and exceptionally high in the beet-top lot. None of these showed calculi. In general, cane fodder, on which several calculi were produced, is higher in silica than alfalfa.

The Ca-P ratio was widest in the alfalfa and beet-top lots, in which there were no gravels.

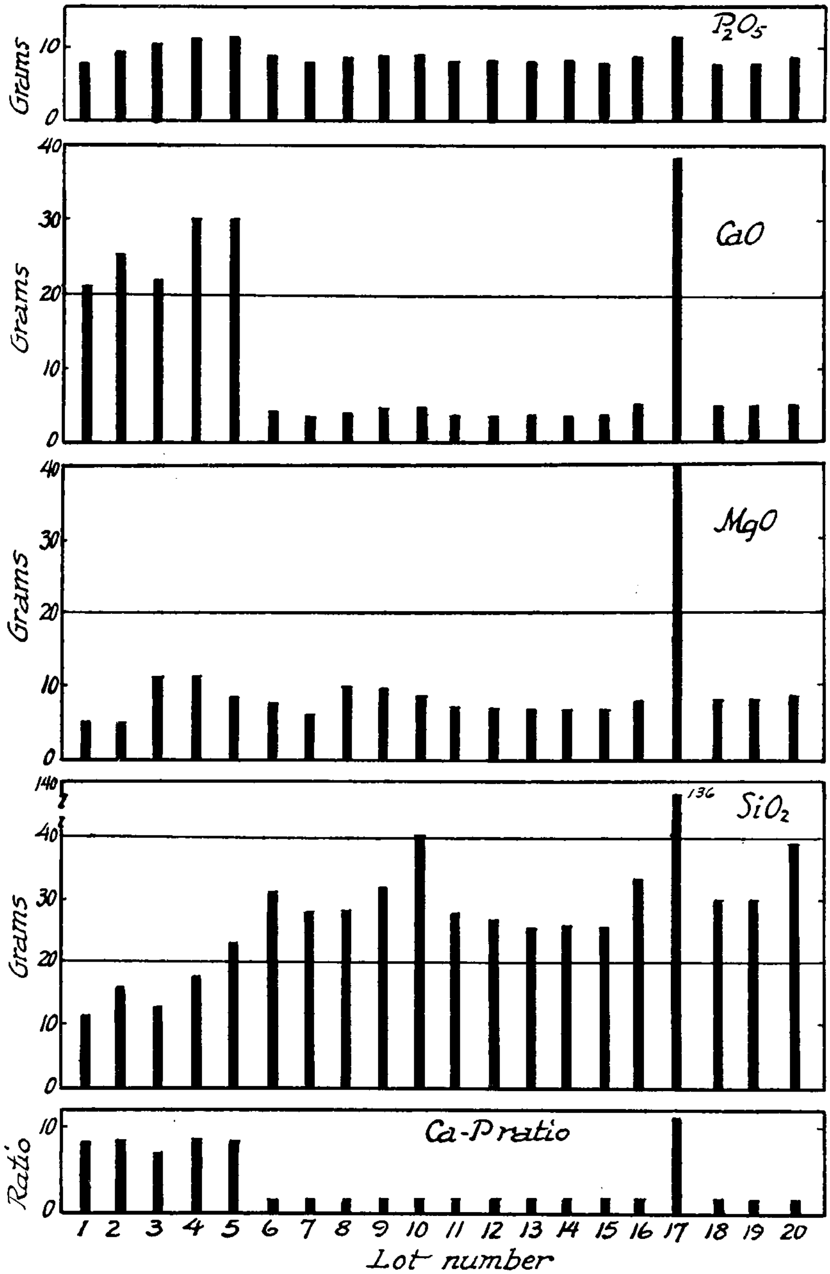

Figure 10.—Intake of minerals and calcium-phosphorus ratio, 1939-40 (per lamb per day by lots).

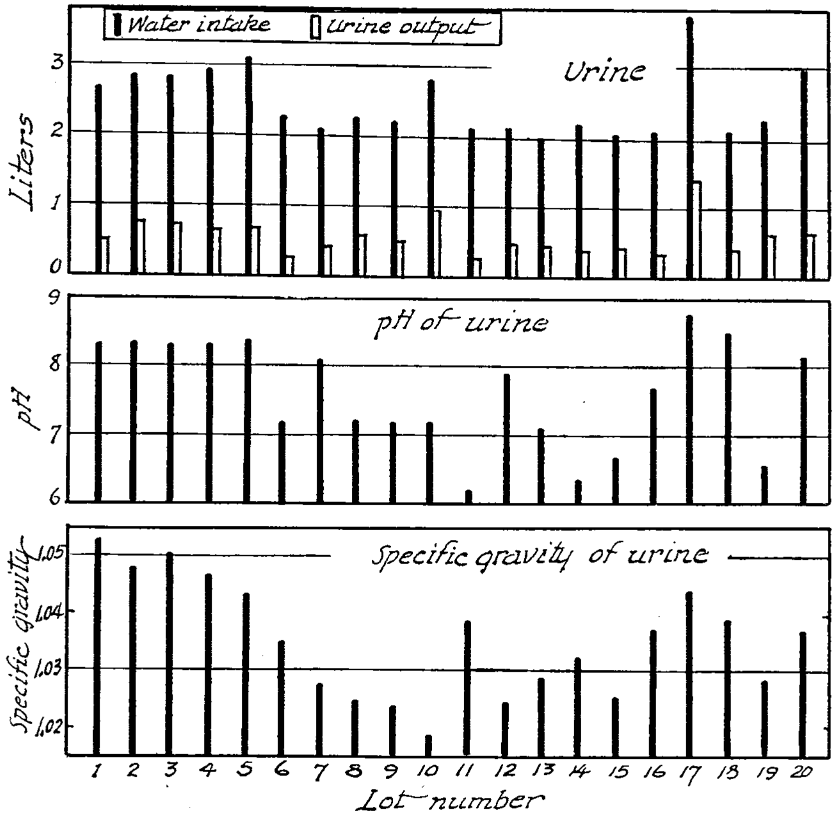

Figure 11.—Water intake and urine output in liters per lamb per day, pH of urine, and specific gravity of urine, 1939-40.

Urine

Water consumption (fig. 11) was high in the alfalfa and beet-top lots, as in the previous experiment, and also in lot 10 (millet hay) and lot 20 ("C" molasses). Urine volume generally paralleled water intake.

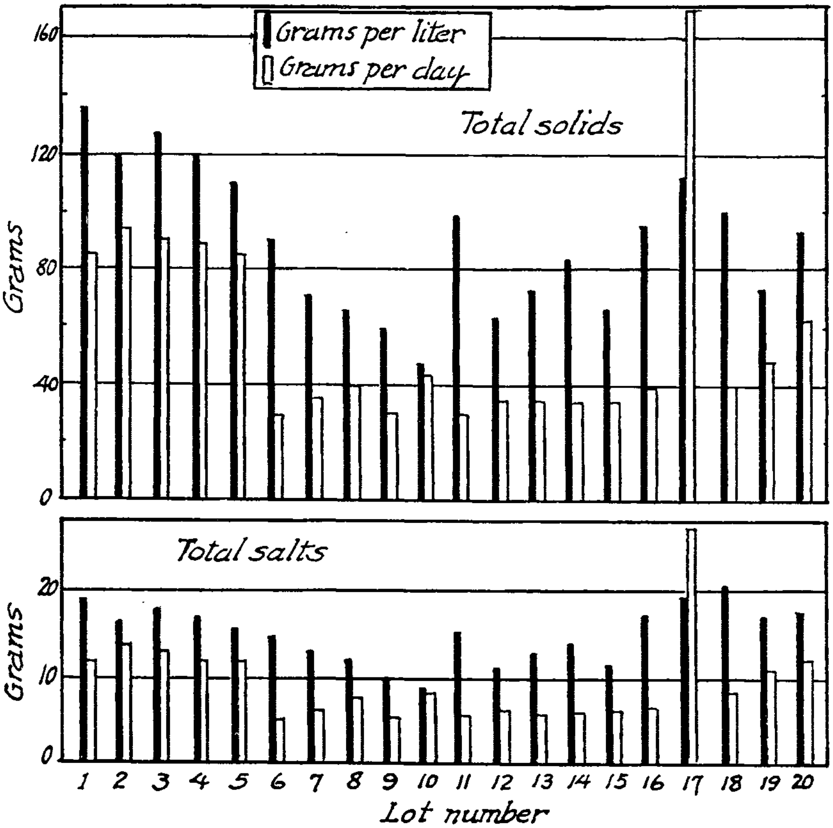

Figure 12.—Total solids and total salts in the urine in grams per liter and grams per day, 1939-40 (average per lamb by lots).

The pH, specific gravity (fig. 11), and total solids (fig. 12) ran parallel, being highest in the alfalfa and beet-top lots.

Sulfur (fig. 13), as was to be expected, was high in lots fed alfalfa and beet tops.

Magnesium concentration was generally low in the alfalfa and beet-top lots. The highest concentration was in lot 11 where there were no calculi.

The highest phosphorus was in lot 9 where there was the largest number of calculi.

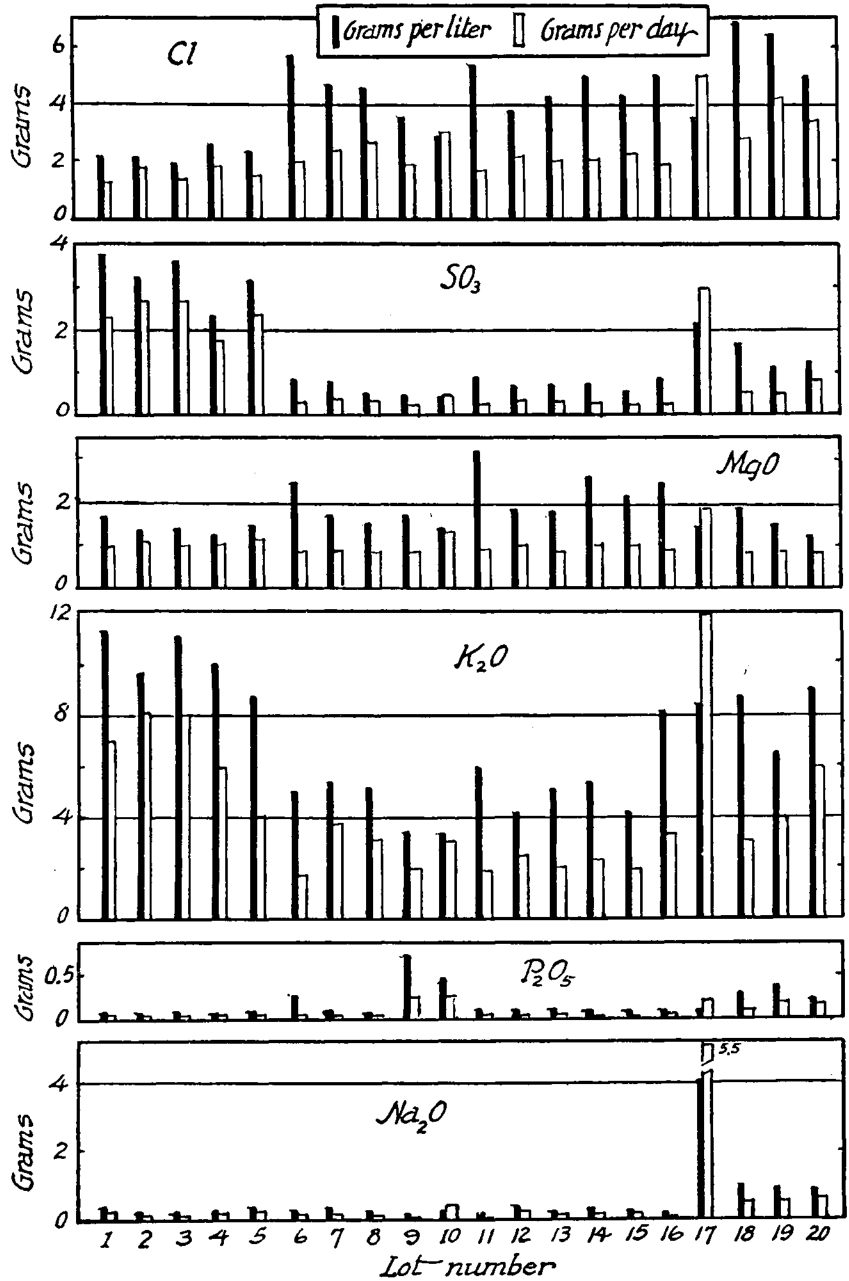

Figure 13.—Minerals in the urine in grams per liter and grams per day, 1939-40 (average per lamb by lots).

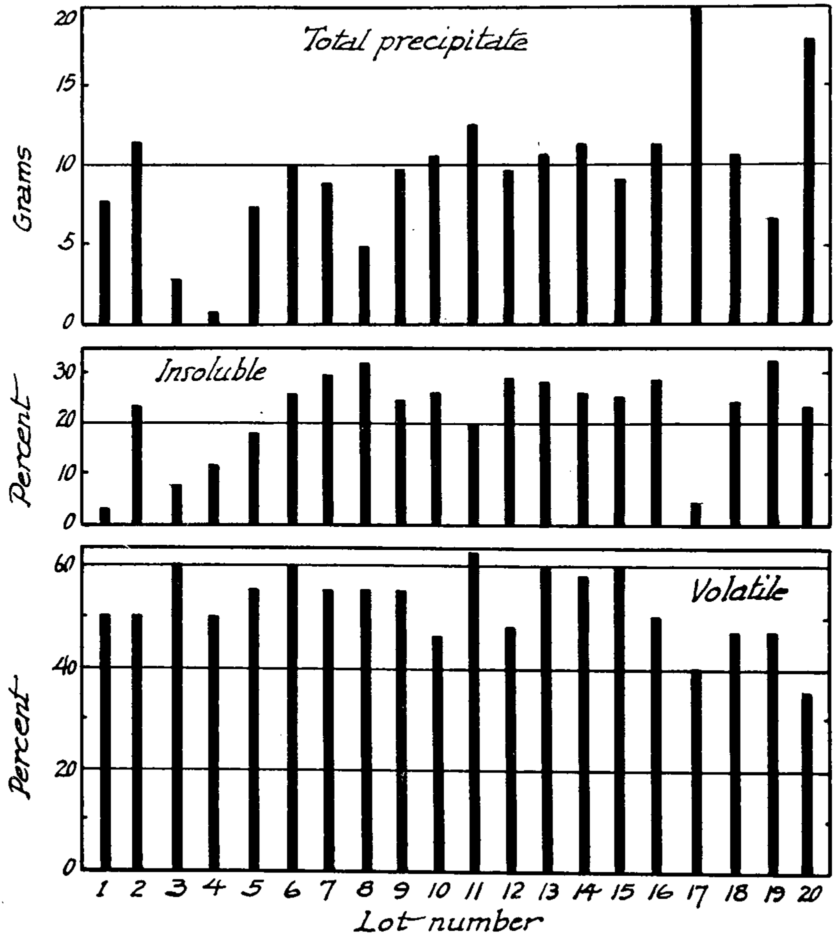

Figure 14.—Total precipitate, insoluble percentage, and volatile percentage in the urine, 1939-40.

Precipitates

The precipitates (fig. 14) which settled from the urine on standing in the refrigerator were kept and then analyzed at the end of the experiment.

Total amount was lowest in lot 4 (milo and alfalfa) and highest in the beet-top lot. Neither lot showed calculi. The solubility was greatest in lots 1 (alfalfa) and 17 (beet tops) and lowest in lots 8 (wheat, bran, cane fodder) and 19 (white corn, cane fodder, molasses). There were no calculi in lots 1, 8, or 17, but there were two in lot 19.

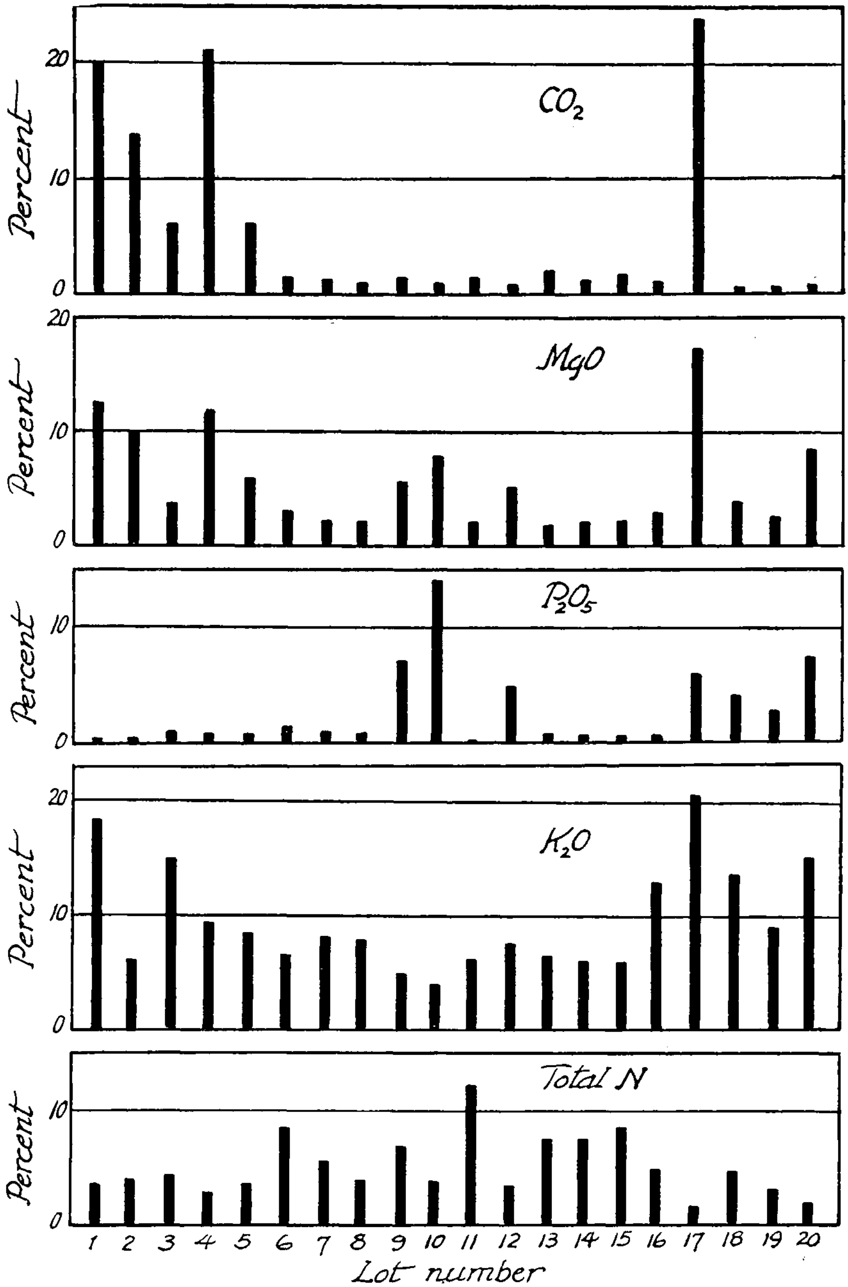

Figure 15.—Percentage of various minerals in the precipitate, 1939-40.

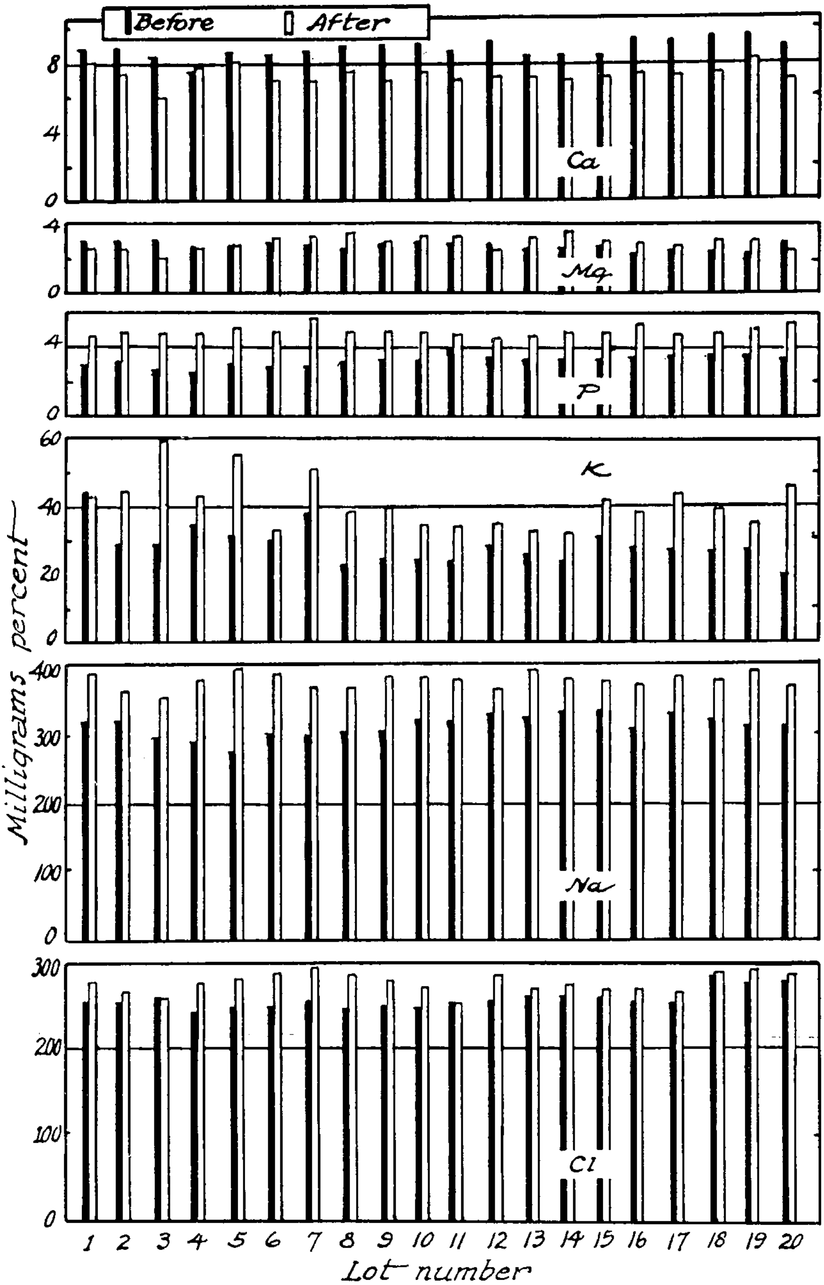

Figure 16.—Minerals in the blood at the beginning and at the end of the 1939-40 experiment (average per lamb by lots).

Phosphorus (fig. 15) was highest in lots 10 (millet, bran, and cane) and 20 (white corn, bran, molasses, and cane). There was one calculus in lot 10 and none in lot 20.

CO_2 was highest in the alfalfa and beet-top lots (fig. 15). Magnesium was also high in the alfalfa and beet-top lots, with no calculi.

Apparently there was nothing significant in either the volatile matter (fig. 14) or total nitrogen (fig. 15).

Blood

A representative number of lambs from each lot were bled at the beginning, near the middle, and at the end of the experiment. Only the first and last bleedings were graphed (fig. 16).

All lots except No. 4 lost calcium during the feeding period. Lot 3 (wheat and alfalfa) was the lowest in this element; for this there seems no adequate explanation.

No significant difference was seen in the magnesium content. Certainly there was no correlation between magnesium and the dedevelopment of calculi.

All lots gained in phosphorus, with No. 7 (barley, bran, and cane) being the highest.

While the graphs for sodium, potassium, and chlorine are presented, there seems to be nothing significant in the findings.

1940-42 Trial

Since there was reason to believe that the previous trials had not been of sufficient length to get sharp and consistent results, the experiment beginning in the fall of 1940 was set up with fewer lambs and in the expectation that it would be continued for 2 years if necessary. Fifteen lambs were divided into five lots, with rations according to table 3. The check lot was as usual on yellow corn and alfalfa. Lots 2 and 3 were on white corn, bran, and cane fodder, differing only in the method of watering. Lot 2 was watered daily and lot 3 every other day. Lot 4 was given the strongest alkali water to be found in this vicinity, the analysis of which follows. Lot

Analysis of alkali water (pH 7.9).

	P.p.m.	Percent of total solids
Volatile	718	12.1
NO_3	50	.5
Cl	70	50.124
Bicarbonates	500	.050
Carbonates	30	.003
CaO	672	11.326
MgO	721	12.150
K_2O	37	.627
Na_2O	599	10.101
Total solids	5,933	

5 was similar to lot 2 except that codliver oil was added. The trial was terminated in 488 days.

TABLE 3.—*Number of lambs developing calculi on different rations, 1940-42.*

Lot No. (3 lambs per lot)	Ration	Average pounds per day	Lamb No.	Days fed	Calculi	Units of vitamin content in livers*	Remarks
	Yellow corn	1.19	88	488	—	25	Slaughtered
1	Alfalfa	1.64	168	488	—	45	Slaughtered
	City water	5.26	90	488	—	50	Slaughtered
	White corn	.85	86	488	+	0	Slaughtered
2	Bran	.22	84	488	+	0	Slaughtered
	Cane fodder	.77	177	201	++++	Not tested	Died
	City water	3.35					
	White corn	.84	92	204	++++	Not tested	Died
3	Bran	.22	87	488	++	trace	Slaughtered
	Cane fodder	.77	197	488	+	0	Slaughtered
	City water (ltd.)	2.99					
	White corn	.88	83	245	+	Not tested	Died
4	Bran	.23	91	467	+++	0	Died
	Cane fodder	1.16	205	488	—	0.5	Slaughtered
	Alkali water	4.40					
	White corn	.86	187	488	+	1	Slaughtered
5	Bran	.22	82	488	++	1	Slaughtered
	Cane fodder	.98	85	488	+++	0.5	Slaughtered
	Codliver oil (cc)	1.33					
	City water	3.76					

*Blue units (7).
+Relative amount in the bladder indicated by number of plus marks.

Results

No lamb in the check lot (corn and alfalfa) developed calculi, and all but one of the others did (fig. 17). The exception was lamb 205 in lot 4 (alkali water), but even here one of the ureters showed an edematous condition that could have been the result of plugging of the lumen. Four of the lambs died during the trial, and in the others the calculi were found at autopsy. The livers of all except those from the check lot, even the ones getting codliver oil, were well depleted of vitamin A. The limitation on water (lots 2 and 3) was apparently insufficient to make any appreciable difference. The ones on alkali water drank more than those of any other except the check lot. It is evident that the amount of codliver oil allowed lambs in lot 5 was insufficient to maintain the vitamin A content of the liver. All these lambs did, however, survive to the end of the experiment.

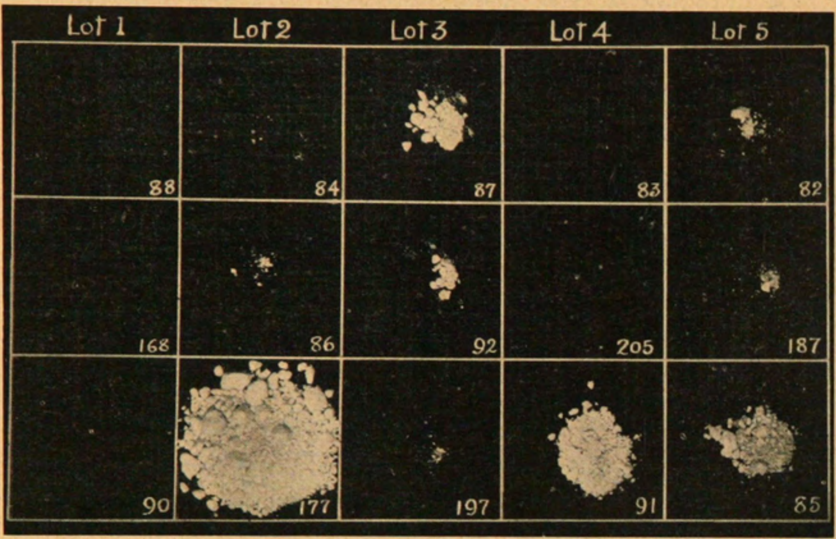

Figure 17.—Calculi found in lambs on test 1940-42. The space for lamb 83, lot 4, is vacant because the calculi from this lamb had been discarded before the picture was taken.

Mineral Intake

The minerals in the rations are graphed in figure 18. The phosphorus and magnesium content of the rations was not appreciably different. Calcium and the Ca-P ratio were high in the check lot (alfalfa) and low in the others. Silica was somewhat higher in lots 4 and 5.

Urine

The usual graphs showing the minerals in the urine in grams per liter and grams per day are shown (fig. 20).

Water consumption and urinary output (fig. 19), as in the preceding trials, were higher in the alfalfa lot. They were next highest in lot 4 (alkali water). Total solids and total salts (fig. 19) were highest in lot 4 (alkali water) and next highest in lot 1 (alfalfa). The specific gravity (fig. 19) was higher in lots 1 (alfalfa) and 4 (alkali water) than in the other three. The concentration of chlorine (fig. 20) was low in the check lot and higher in the others. Sulfur (fig. 20) was exceptionally high in lot 4 (alkali water). Potassium (fig. 20) was high in lots 1 and 4. Total nitrogen (fig. 19) was highest in lot 1. Phosphorus (fig. 20) was exceptionally high in lot 5. Magnesium (fig. 20) was low in lot 1 and highest in lot 4 (alkali water).

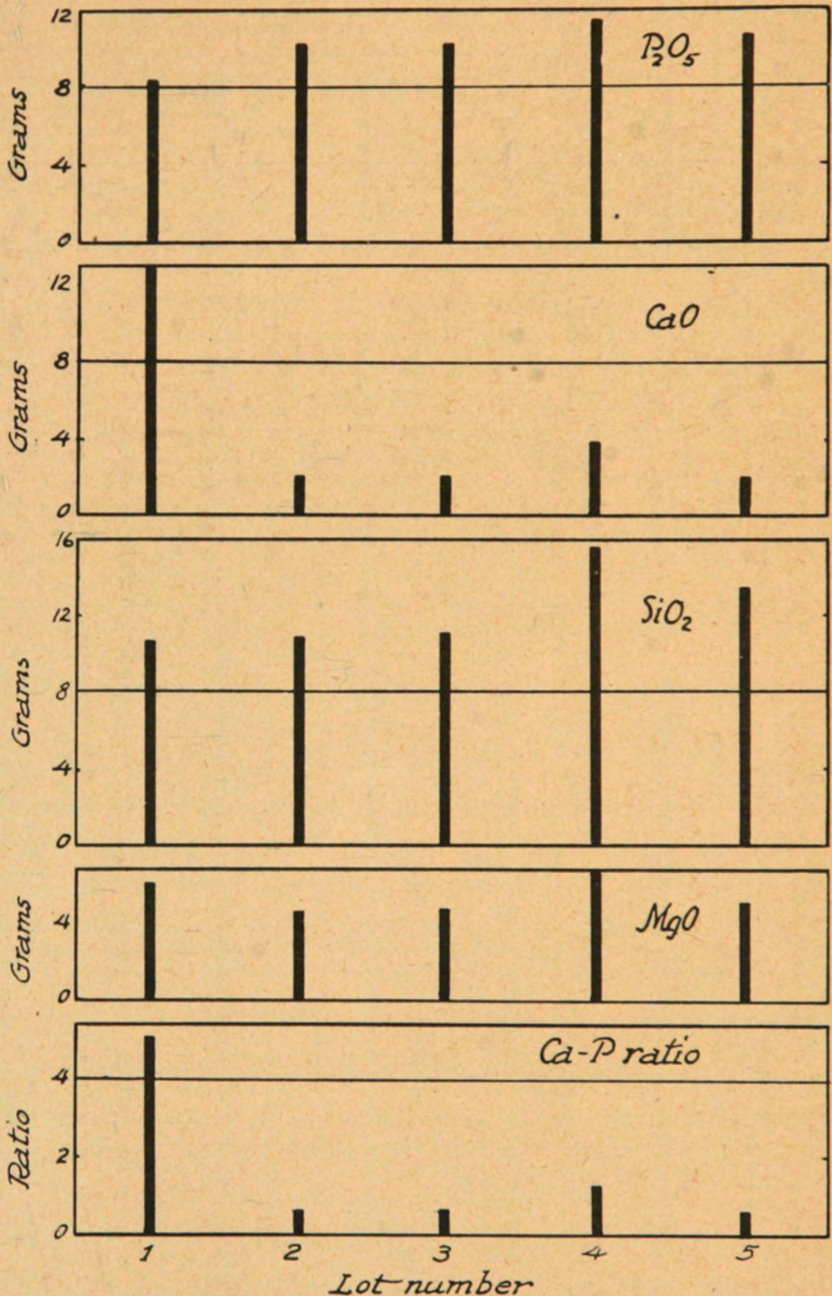

Figure 18.—Intake of minerals and calcium-phosphorus ratio, 1940-42 (per lamb per day by lots).

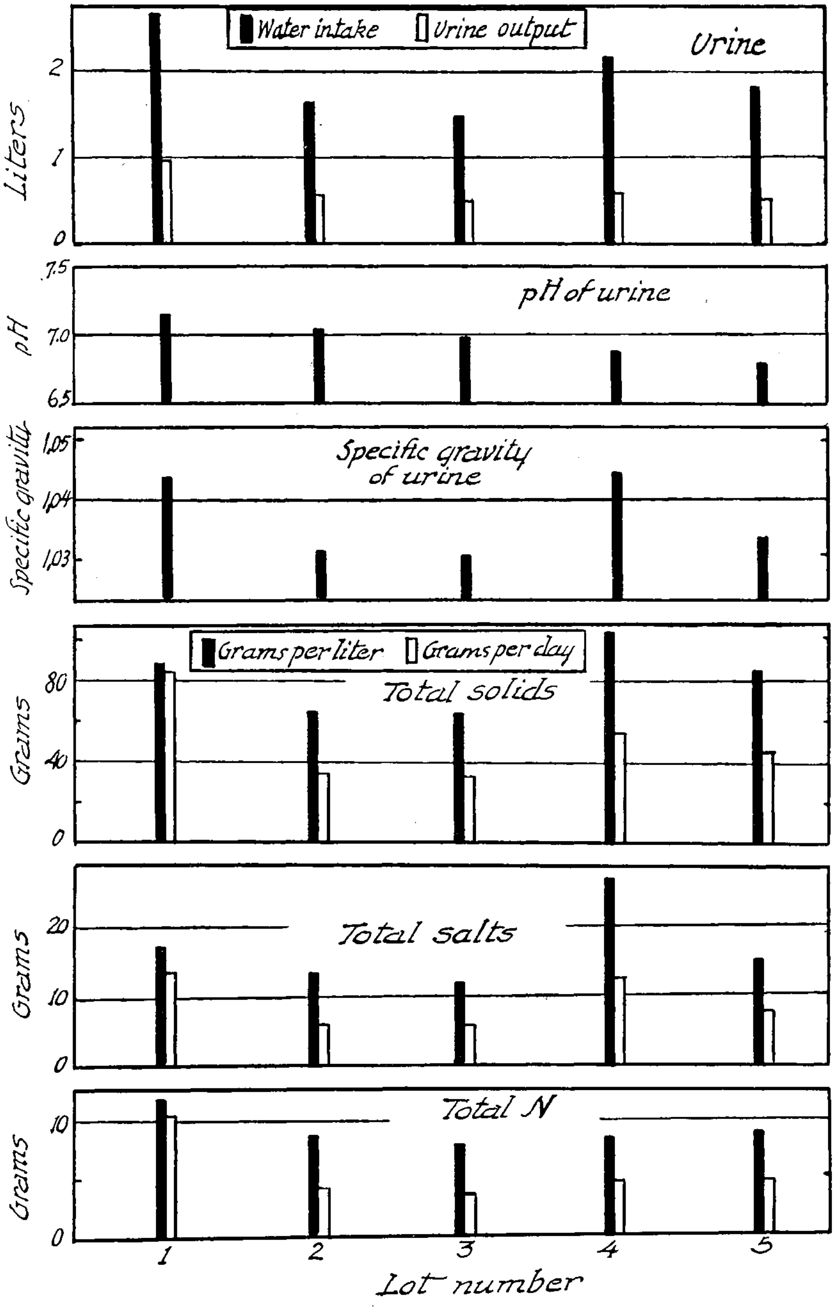

Figure 19.—Water intake and urine output in liters per lamb per day, pH of urine, specific gravity of urine (average per lamb by lots), and total solids, total salts, and total nitrogen, 1940-42.

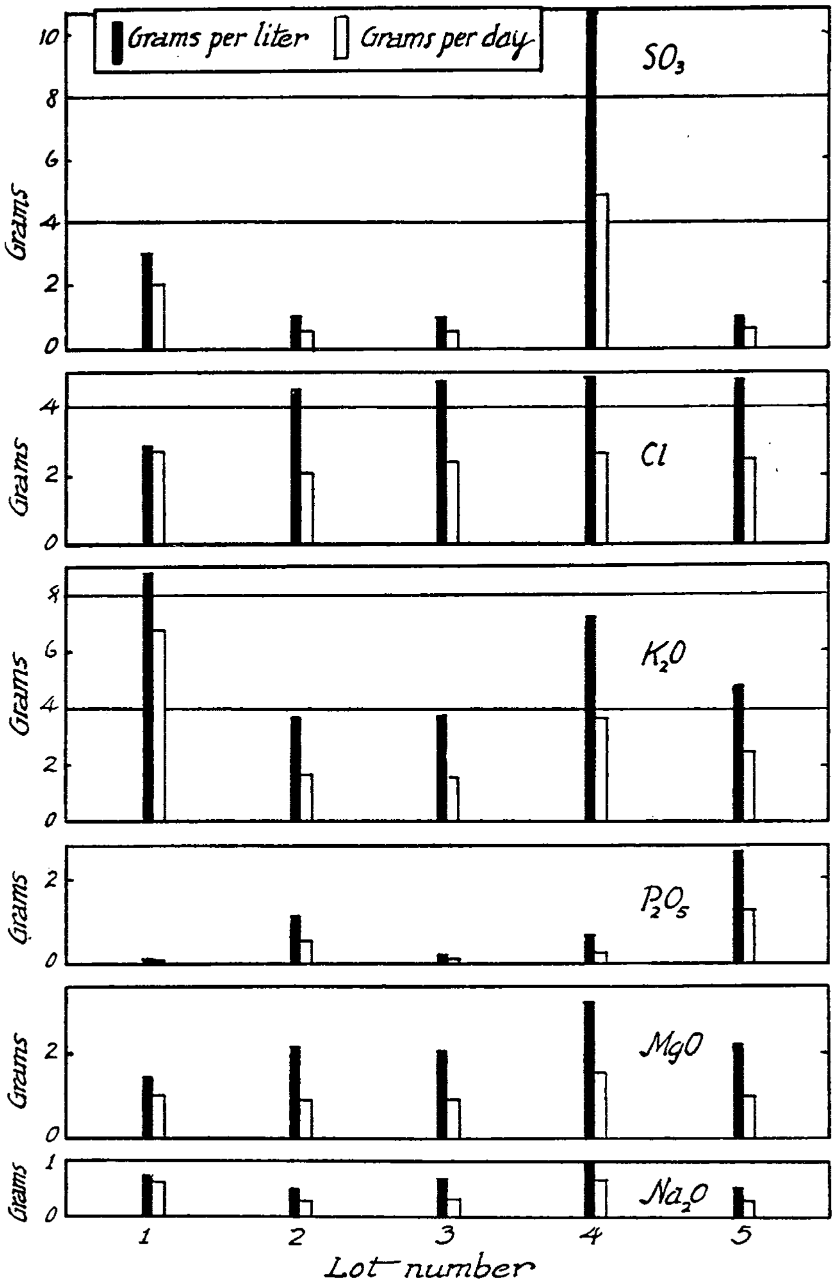

Figure 20.—Minerals in the urine in grams per liter and grams per day, 1940-42 (average per lamb by lots).

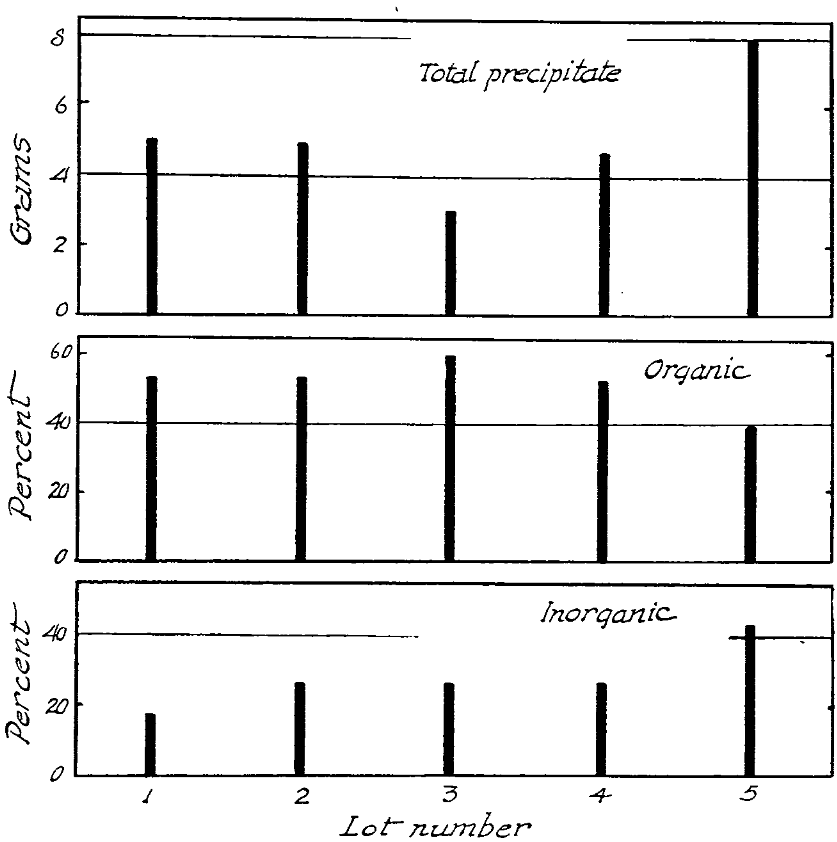

Figure 21.—Total precipitate in the urine, and percentage of organic and inorganic material, 1940-42.

Precipitates

The precipitates were collected for a period of 69 days (fig. 21). The total amount was highest in lot 5 (codliver oil). The organic matter was low in lot 5. The silica (fig. 22) was low in lot 1 and next lowest in lot 5 (codliver oil). Calcium was highest in lots 4 and 5, and phosphorus was very high in lot 5. Sulfur was highest in lot 4 (alkali water), and magnesium was high in lots 1 (alfalfa) and 5 (codliver oil).

Blood

The lambs were bled seven times during the experiment, and calcium, phosphorus, magnesium, sodium, chlorine, and sulfur were determined (fig. 23). Only calcium, phosphorus, and magnesium are presented. The chief point of interest is the loss of phosphorus in all lots, this loss being greatest in lot 1 (alfalfa and corn).

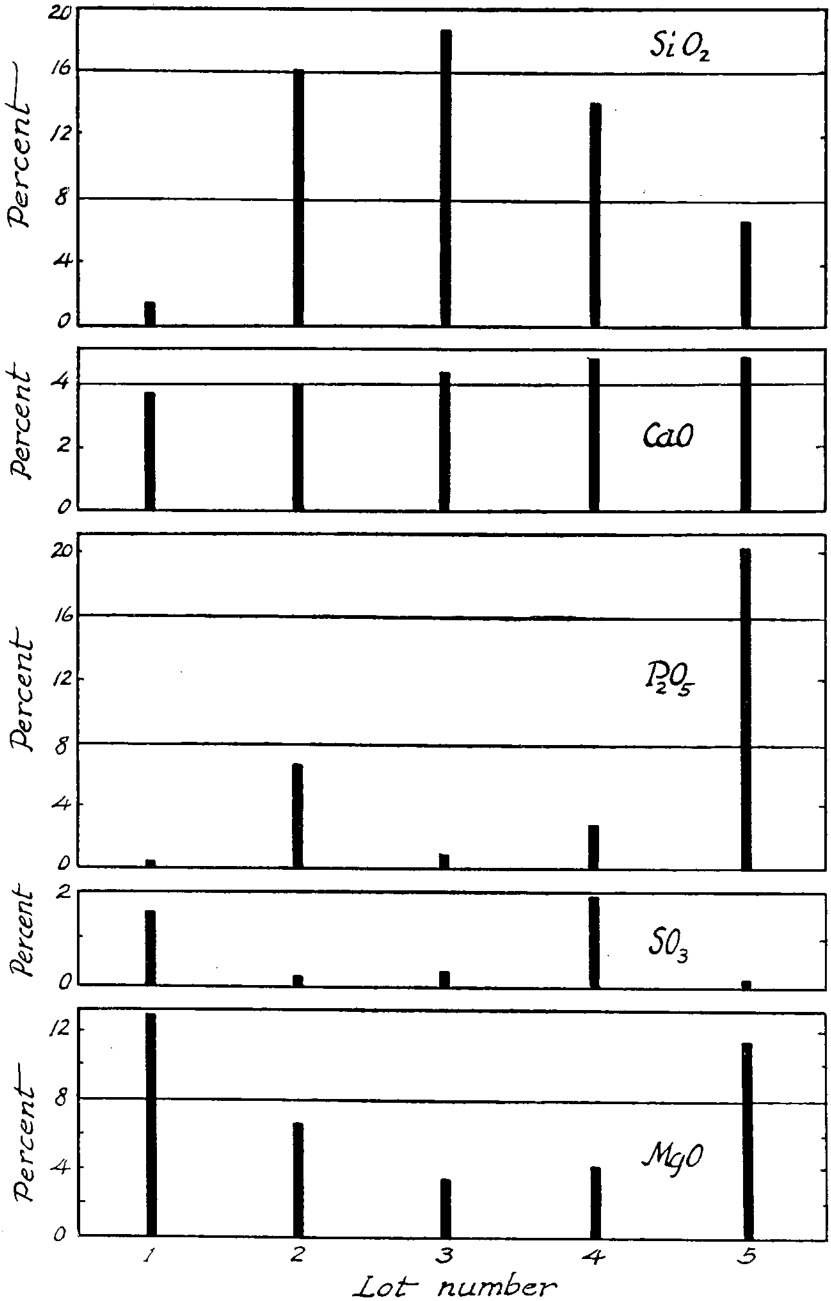

Figure 22.—Percentage of various minerals in the precipitate, 1940-42.

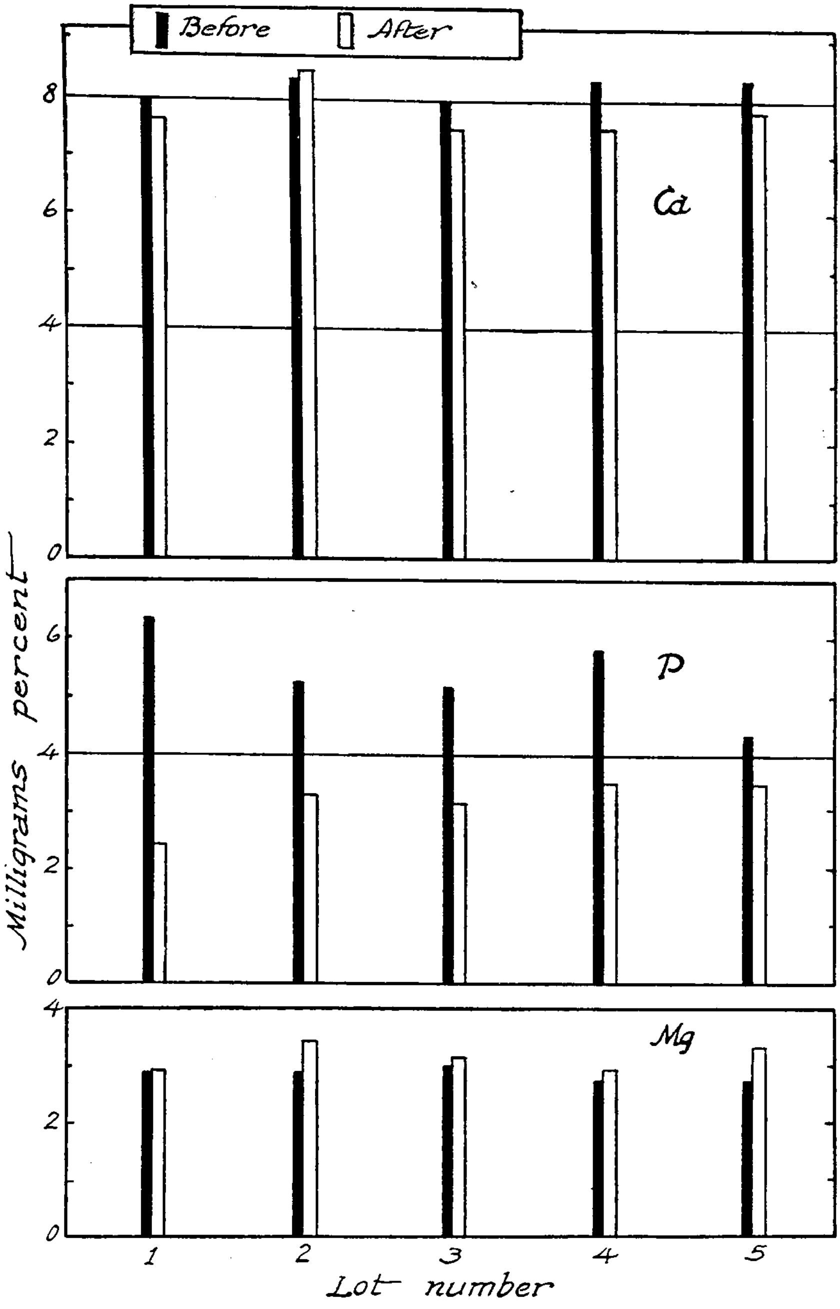

Figure 23.—Calcium, phosphorus, and magnesium in the blood at the beginning and at the end of the 1940-42 experiment (average per lamb by lots).

1942-43 Trial

Clinical experience having cast suspicion on forced feeding of minerals, especially to creep-fed lambs, the 1942-43 test was set up to explore that field. Twenty nursing lambs, weighing from 20 to 65 pounds each, were divided into four lots of five each. All were fed a basic ration of good-quality alfalfa (second and third cuttings), rolled barley, and salt. The barley was started at 0.2 pound and gradually increased to a maximum of 1.3 pounds, average 0.94 pound. The mineral constituted 4 percent of the barley ration in each case and was mixed with it. To lot 2 was added a commercial calcium carbonate guaranteed to contain 97 percent of that substance. To lot 3 was added magnesium carbonate manufactured by a well-known chemical concern. For lot 4 a commercial mixture of the following advertised composition was used:

	Percent		Percent
Sulphur	5	Limestone	24.97
Common salt	10	Copperas	3.0
Spent boneblack	14	Potassium iodide	0.09
Steamed bonemeal	20	Anise	1.0
Iron oxide	2	Charcoal	3.0
Glaubers salt	5	Soybean oil meal	10.0
Epsom salt	2		

As the lambs got fat they were slaughtered and carefully examined. No clinical cases of calculi developed in a feeding period that was on the average 200 days. Small sand particles were found in the calyces of each kidney in one lamb in lot 2 (calcium carbonate) and small grains were found in both kidneys of one lamb in lot 3 (magnesium carbonate). No evidence of calculi was found in either lots 1 or 4. Examination of the livers by the antimony trichloride method showed a plentiful supply of vitamin A (70 to 300 blue units).

The blood was examined for calcium, phosphorus, and magnesium six times during the feeding period, but since no significant change took place in any of these elements the data are not presented.

Composition of Calculi

Scott (*15*) in 1923 stated that calculi from sheep were composed of phosphates.

Pontius, Carr and Doyle (*13*) in 1931 said that "the concretions were composed of calcium phosphate or aluminum silicate, largely the former".

Shaw (*16*) said in 1937 that 95 percent of the inorganic matter in the stones was silica.

Beeson, Pence and Holm (3) reported in 1943 that from 70 to 80 percent of the calculi in four sheep was composed of silica. Most of the remainder was organic matter. There were small amounts of calcium, magnesium, and iron but no phosphorus.

It is often difficult to get sufficient material from frank cases of calculi for a quantitative test. The following analyses are presented in percentages:

Date	Lamb No.	MgO	P_2O_5	CaO	Al_2O_3	Silica	Organic
2-16-37	Field case	15.0	56.0	7.0	24.0	0.3	....
1-31-38	Field case	10.4	32.1	5.56	7.53	....	....
2-28-38	Field case	16.8	31.65	3.17	....	....	....
			1938-39 Experiment				
	607	6.93	13.08		....	0.88	....
	608	20.18	26.35		....	0.36	....
	612	20.45	32.27		....	7.06	....
	613	26.37	35.36		....	3.3	....
	616	22.00	29.67		....	0.49	....
			1940-42 Experiment				
	177	29.39	38.23		....	0.17	27.9
	87	....	....		....	80.00	17.2
	92	....	....		....	81.11	17.95
	91	29.35	38.03		....	1.16	27.6
	82	5.09	6.64		....	69.00	18.88
	85	3.03	3.99		....	67.38	23.4

While a qualitative examination was made of eight calculi from the 1939-40 experiment, the amount in each case was insufficient for a quantitative test.

An estimate from the qualitative examination was also made from one of the cases in the 1942-43 test. It seemed to be about half organic matter and half magnesium phosphate. There was no silica and no calcium.

The evidence seems to be that calculi in sheep are chiefly composed of magnesium phosphate or silica. Nothing in this work points to reasons for a predominance of one or the other.

Location of Calculi

In the 11 animals that died or were killed in extremis, 9 showed obstruction in the urethral process or just back of it. Of these, three had the entire urethra filled with calculi and one showed a further obstruction at the ischial arch. Two animals showed the obstruction at the sigmoid flexure of the penis. One had an obstruction in one of the ureters. Five showed numerous calculi in the bladder. Since most animals had a rupture of this organ at the time of death it is quite possible that pre-existing calculi had been thrown out into the peritoneal cavity.

Of the seven animals slaughtered at the end of the 1940-42 experiment, six showed flaky calculi in the calyces of one or both kidneys and one showed a plugged ureter.

From the work of others, a large clinical experience of our own, and the observations in connection with these tests, it seems evident that calculi in sheep form in the tubules of the kidneys and not in the bladder as previously supposed.

Summary and Discussion

Rations

In all trials except the last, alfalfa seemed to prevent the development of calculi. It is true that the four lambs out of lot 6 in the first test showed symptoms after being changed to alfalfa and yellow corn but they had been on cane fodder, bran, and white corn for 126 days prior to that time. In the 1942-43 test one lamb developed stones in the lot getting 4 percent of magnesium carbonate, and one in the lot getting 4 percent of calcium carbonate, although both lots had access to all the alfalfa the lambs would eat.

With one exception the Nebraska work indicated that as little as one-half pound of alfalfa per day was protective. It is possible that in that one exception the hay was of poor quality or that one-half pound is close to the minimum requirement.

Beet tops were fed in only two trials and then to only one lot in each. In neither did gravels develop. The Nebraska workers, however, reported several calculi on beet-top silage. Our work seemed to indicate that beet tops required more water consumption and thus a greater flow of urine. It would be interesting to know the vitamin A content of the Nebraska tops as compared with our own.

Cane fodder seemed to be quite effective in the production of calculi since all affected lambs were on that forage except in the 1942-43 trials with calcium carbonate and magnesium carbonate.

In only the first test was a clear distinction set up between yellow and white corn. By the end of the 120 days one lamb in each lot had developed gravels. Probably if there is any difference in the protective quality of these two kinds of corn it is resident in the vitamin A content.

In only the last test did any lamb which was not getting bran develop calculi. The Purdue work has cast suspicion on that concentrate. If it is a factor it is because of the production of insoluble phosphates in the urine.

In no lot receiving beet molasses did calculi develop, but in those getting cane and corn molasses gravels were found. The beet molasses seemed to require a greater water consumption.

Finally it may be said that cane hay, white corn, and bran were most likely to result in calculi formation.

Vitamin A

Only in the 1942-43 trial did any lamb come down with gravels that was getting an adequate amount of vitamin A. The work in Texas and Oregon clearly supports the view that vitamin A deficiency is involved in development of urinary calculi since those tests were planned to explore vitamin A deficiency, and the development of calculi was incidental.

In the first of the Nebraska tests the lambs were deficient when they were placed on feed. In only one instance did one-half pound of alfalfa not prove protective. In the 1942-43 test by that station, however, a commercial product containing carotene only delayed the development of calculi. It is possible that sheep do not readily use carotene in that form (*10*). We used codliver oil in the 1940-42 test but it was not effective either in the prevention of calculi or the maintenance of the vitamin A content of the liver.

The Idaho workers produced calculi in the presence of adequate amounts of vitamin A as did we in our 1942-43 work.

Water Consumption

In all three of the trials the lambs consuming the largest amount of water and excreting the greatest amount of urine showed no calculi. Alfalfa and beet tops seemed always to be associated with high water intake. In the 1939-40 experiment the lambs in lot 10 (millet hay) drank as much water as those in lot 1 (alfalfa) and excreted more urine, yet one lamb developed calculi. In lot 20 (''C'' molasses) the lambs consumed more water than in lot 1, but showed no gravels. In 1940-42, lot 4 (alkali water), the lambs drank nearly as much water as lot 1 (alfalfa) and more than the other three lots, yet two out of the three lambs developed calculi.

Calcium

As was to be expected, calcium was always higher in alfalfa and beet tops (no calculi) than in cane fodder. The Ca-P ratio was also higher in those lambs fed alfalfa and beet tops. No appreciable amounts of calcium were discovered in the urine in any case. The variations in the blood serum were too small to be significant.

Phosphorus

Beet tops (no calculi) were high in phosphorus. Otherwise there was no considerable difference in the intake of this element in the various lots of the several trials.

In the urine the phosphates were quite low in all lots in the first test. In the second test they were highest in lot 9 which had the greatest number of gravels and next highest in lot 10 (one affected lamb) and lot 18 (two affected). In the third experiment they were quite high in lot 5 (codliver oil) but higher in all lots showing calculi than in the check lot (alfalfa).

The precipitate showed the largest phosphorus content in lots 5 (cane fodder, one calculus) and 4 (beet tops, no calculi) of the first test. In the second test it was highest in lot 10 (hay millet, one calculus) and lot 9 (milo, three calculi). It was next highest in lots 20 ("C" molasses) and 17 (beet tops), neither of which had calculi. In the third test the precipitate paralleled the urine in that phosphorus was highest in lot 5 (codliver oil) and lowest in lot 1 (alfalfa).

In the blood in the first test there was little variation either between lots or between the tests made at the beginning and at the end of the experiment. In the second trial all lots gained in phosphorus and about equally. In the third test all lots lost, but the check lot (alfalfa) most of all and the codliver oil lot, in spite of excreting most phosphorus in the urine, lost the least.

It can hardly be said that phosphorus bears any direct relation to the formation of calculi.

Magnesium

In the first trial the magnesium content of the rations on which calculi developed was lower than in the alfalfa lots. This was not borne out in the second trial. Beet tops were consistently high in magnesium content but no lamb on beet tops developed calculi.

There was some evidence of a greater concentration of magnesium in the urine in those showing calculi in the first and third trials but even this was not borne out in the second experiment. Magnesium was consistently high in the urine precipitates from all lots on alfalfa and beet tops where there were no stones.

In the first experiment the cane fodder lots showed a higher percent of magnesium in the blood at the end of the period but the difference in further trials was not marked.

Finally, 4 percent of magnesium carbonate when added to the grain ration did not materially increase the magnesium content of the blood, but one of the lambs on this ration did show small grains of sand in the kidneys on slaughter.

Precipitates

The total precipitate on standing was greatest in the beet-top lots, but the amount seemed to bear no relation to the development of calculi in the experiments as a whole.

In general the insoluble portion was greater in those lambs on cane fodder, corn, and bran, which lots showed the largest number of calculi.

Silica

There has been much discussion of the place that silica has in the production of calculi. In Oregon and in Idaho the calculi examined were high in this substance. Some of the calculi in our work also contained appreciable amounts. The data here presented show no relationship between the intake of silica and the formation of calculi. The examination of the whole urine did not include search for SiO_2. However, if the insoluble substances in the precipitates are considered to be largely silica, there does seem to be a definite correlation. These findings suggest further research in this line.

Conclusions

A ration composed of cane fodder, bran, and white corn seems more likely to produce urinary calculi in lambs than one containing alfalfa or beet tops and yellow corn.

Such a cane fodder-bran-white corn ration is low in vitamin A, has a narrow Ca-P ratio, requires little water consumption, and results in a small urine output.

The urine from animals on this ration is more nearly neutral, is low in total solids and specific gravity, and on standing precipitates out a large proportion of insoluble matter.

There is some indication that calculi may develop in the presence of adequate amounts of alfalfa when excessive amounts of calcium carbonate and magnesium carbonate are fed in the form of a mineral supplement.

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