June 1, 1954

To the Graduate Council:

I am submitting herewith a thesis written by Harmon E. Galey entitled "The Use of Aluminum Sulfate Hydrate in the Alleviation of the Effects of Abnormally Increased Levels of Fluorine Ingested by Cattle and Sheep." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Animal Husbandry.

Charles A. Hobbs
Major Professor

We have read this thesis
and recommend its acceptance:

L V Skold

O. E. Goff

M. C. Bell

Accepted for the Council:

E. A. Watson
Dean of the Graduate School

THE USE OF ALUMINUM SULFATE HYDRATE IN THE ALLEVIATION OF THE EFFECTS OF ABNORMALLY INCREASED LEVELS OF FLUORINE INGESTED BY CATTLE AND SHEEP

A THESIS

Submitted to
The Graduate Council
of
The University of Tennessee
in
Partial Fulfillment of the Requirements
for the degree of
Master of Science

---

by
Harmon E. Galey

June 1954

2R
33

ACKNOWLEDGMENT

The writer wishes to express his sincere appreciation to Dr. C. S. Hobbs and Dr. M. C. Bell for their guidance, encouragement and many suggestions in preparing this thesis.

The writer is indebted to Dr. H. J. Smith for his able assistance and suggestions in the compilation of the analyzed statistics in this work.

Special acknowledgment is due Dr. G. M. Merriman and Dr. R. P. Gregory, Jr., for the veterinary work in connection with this thesis.

The writer wishes to thank Professor J. W. Cole for making facilities available and aiding in sacrificing and slaughter of animals.

354270

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION	1
II.	REVIEW OF LITERATURE	3
III.	EXPERIMENTAL PROCEDURE	9
	Cattle	9
	Sheep	17
IV.	RESULTS AND DISCUSSION	21
	Cattle	21
	Feed consumption	21
	Weight gains	23
	Digestibility	25
	Balance studies	25
	Reproduction	28
	Fluorine content of bones	31
	Teeth examinations	35
	Sheep	38
	Feed consumption	38
	Weight gains	40
	Reproduction	40
	Fluorine content of bones	42
V.	SUMMARY	47
	BIBLIOGRAPHY	49
	APPENDIX	52

LIST OF TABLES

TABLE		PAGE
I.	Plan of Cattle Experiment	11
II.	Plan of Sheep Experiment	19
III.	Average Daily Feed Consumption of Cattle Fed Various Levels of Fluorine and Aluminum Sulfate	22
IV.	Average Daily Gains of Cattle Fed Various Levels of Fluorine and Aluminum Sulfate	24
V.	Average Apparent Digestion Coefficients for Cattle Fed Various Levels of Fluorine and Aluminum Sulfate	26
VI.	Average Daily Fluorine Balance of Cattle Fed Various Levels of Fluorine and Aluminum Sulfate	27
VII.	Average Daily Balance of Calcium, Phosphorus and Nitrogen for Cattle Fed Various Levels of Fluorine and Aluminum Sulfate	29
VIII.	Summary of Average Daily Gains and Birth Weights of Calves Produced by Cows Fed Various Levels of Fluorine and Aluminum Sulfate	30
IX.	Fluorine Content of Ribs of Cows Fed Various Levels of Fluorine and Aluminum Sulfate	33

LIST OF TABLES (continued)

TABLE PAGE

X. Fluorine Content of Calf Bones Produced by Cows Fed Various Levels of Fluorine and Aluminum Sulfate 34

XI. Comparison of Current Teeth Classifications of Cattle Fed Various Levels of Fluorine with and without the Addition of Aluminum Sulfate 36

XII. Average Daily Feed Consumption of Sheep Fed Various Levels of Fluorine and Aluminum Sulfate 39

XIII. Average Daily Gains of Sheep Fed Various Levels of Fluorine and Aluminum Sulfate 41

XIV. Summary of Average Daily Gains and Birth Weights of Lambs Produced by Ewes Fed Various Levels of Fluorine and Aluminum Sulfate 43

XV. Average Fluorine Content of Bones from Sheep Fed Various Levels of Fluorine and Aluminum Sulfate 45

LIST OF TABLES (continued)

TABLE PAGE

XVI. Fluorine Content of Lamb Metacarpal Bones from Ewes Fed Various Levels of Fluorine and Aluminum Sulfate 46

XVII. Average Daily Ingestion of Fluorine and Aluminum Sulfate by Cattle 53

XVIII. Average Daily Fluorine Balance of Individual Animals Fed Various Levels of Fluorine and Aluminum Sulfate 54

XIX. Classification of the Effects of Dietary Fluorine on Teeth of Cattle 55

XX. Average Daily Ingestion of Fluorine and Aluminum Sulfate by Sheep 57

XXI. Fluorine Content of Bones from Sheep Fed Various Levels of Fluorine and Aluminum Sulfate 58

CHAPTER I

INTRODUCTION

Fluorosis has been defined as "chronic poisoning with fluorine", by the American Illustrated Medical Dictionary. A more suitable definition might be: any condition resulting from the prolonged ingestion of fluorine above normal levels of intake in sufficient amounts to be harmful to the animal.

The problem of animals ingesting abnormally increased levels of fluorine is of considerable importance in livestock production. The problem arose through the feeding of raw rock phosphate containing 3 to 4 per cent fluorine. Fluorine, when fed in large amounts, caused cattle to lose their appetite, gain poorly or lose weight. The teeth of young cattle may become mottled and pitted.

Many countries including the United States have reported chronic fluorosis in cattle and sheep grazing in the vicinity of certain industrial plants. Aluminum reduction works, brick plants, fertilizer plants and other types of industrial plants using a fluorine containing material in their processing operations have been reported to emit fluorine compounds.

There have been many experiments conducted to determine the detrimental effects of excess levels of fluorine on laboratory animals. However, there has been comparatively little research done to seek out alleviators or antidotes that will protect animals for extended periods from excessive levels of fluorine.

The purpose of these experiments was to study the effectiveness of aluminum sulfate hydrate in reducing the harmful effects of excessive amounts of fluorine being ingested by cattle and sheep. Various phases of these experiments included the effects on:

1. Feed consumption.

2. Weight gains.

3. The ability of cattle to digest crude fiber, crude protein, ether extract, and nitrogen-free extract.

4. Metabolic balance of fluorine, calcium, phosphorus, and nitrogen in cattle.

5. Reproduction and performance of calves and lambs.

6. Storage of fluorine in the bones.

7. Teeth.

The experiment with cattle is in progress at this time and experiments with sheep have been completed.

CHAPTER II

REVIEW OF LITERATURE

According to Roholm (1937) the detrimental effects of excessive amounts of fluorine were recognized before this element was isolated in 1886 by Moissan. Since that time many studies have been conducted to determine some of the effects of fluorine on man and animals. However, many of these studies have been under field conditions and not in well controlled experiments. Excellent reviews of most of these studies have been presented by Mitchell and Edman (1952), Schmidt and Rand (1952), Roholm (1937), and McClure (1933).

Fluorine studies with animals have been made primarily with rats, swine, sheep and cattle, with a few reports of studies on dogs, rabbits and horses. Although there have been controlled feeding experiments with cattle fed various levels of fluorine materials, very few studies have been reported on materials that may alleviate fluorosis in cattle or sheep.

Agate et al. (1949), in a survey of the Fort Williams area of Scotland, reported marked chronic fluorosis in cattle and sheep, with symptoms of excessive tooth wear, lowered gain in weight, reduced milk production, and general poor health. A sample of herbage, which these animals had been consuming, contained sixty-one ppm fluorine on a dry weight basis.

Maynard (1951) stated that harmful effects of practical importance in livestock feeding arise from the continuous ingestion of comparatively

minute amounts of fluorine in water or in rations supplemented with mineral phosphates high in fluorine. He further states that although injuries to the bones and teeth are the initial or most evident effects of fluorine, higher intakes or long continued feeding interferes with feed consumption, growth and milk production.

Agate et al. (1949), Bauer et al. (1945), Blakemore et al. (1948), Majumdar et al. (1943) and McClure et al. (1933) reported symptoms correlated with fluorosis such as dryness and stiffness of hide, poor condition of the hair coat, elongated hooves, diarrhea, anorexia, decreased weight gain, emaciation and cachexia. According to Schmidt and Rand (1952), none of these symptoms are unique in fluorosis, and the validity of them as indexes of fluorosis should be checked by correlation with teeth and bone involvement as well as confirmation through laboratory analysis for fluorine in feed, drinking water, urine and bones.

Sharpless (1936) reported that aluminum chloride was found to inhibit, to a large extent, the toxic effects of fluorine in rats. Salts of lauthanum, cerium, thorium and boron, which form insoluble or complex fluorides, were found to give either no protection, or as in the case of lauthanum, only slight protection.

In these studies Sharpless used levels of 0.025 per cent and 0.1 per cent sodium fluoride and 0.5 per cent and 2.0 per cent aluminum chloride in the diet. The group fed 0.1 per cent sodium fluoride grew at approximately two-thirds the normal rate, but by adding 0.056 per cent aluminum chloride to their diet, normal growth was obtained. Also, rats fed the diet containing 0.1 per cent sodium fluoride had incisors

with a rough and often pitted surface, and sections of the enamel were often chipped. However, rats fed this same diet with 0.5 per cent aluminum chloride had incisors with a smooth surface, but they were bleached and the lowers wore down rapidly. It was assumed that aluminum is not absorbed by the rat. Therefore, the protective action must take place in the intestinal tract, probably by the formation of a slightly dissociated compound of aluminum and fluorine.

Sharpless also reported that 1.0 per cent calcium carbonate gave some protection, and 2.0 per cent caused normal growth in rats receiving 0.1 per cent sodium fluoride. Two per cent calcium carbonate gave no significant protection to the incisors. The addition of 1.0 per cent calcium chloride caused a lower rate of growth than was obtained from sodium fluoride alone.

Marcovitch and Stanley (1942) reported that aluminum sulfate and hydrated lime are capable of saving animals from a lethal dose of sodium fluoride. Boric acid also had some value as an antidote through the formation of a fluoroborate. The aluminum sulfate forms cryolite, which is found to be much less toxic.

Majumdar and Ray (1946) reported that the addition of calcium or phosphorus salts, in amounts sufficient to bring the quantity of and the ratio between the two minerals to optimum levels, helped in protecting the animals for long periods against fluorine intoxication. A large positive balance of fluorine was observed in all animals given high quantities of the element. The estimation of net retention of

fluorine gave no indication of the condition of the animal. However, the poorer the condition of an animal, the greater the quantity of fluorine excreted in the urine. These workers concluded that urinary output of fluorine is a good index of the intensity of fluorine intoxication.

Majumdar and Ray further state that the addition of aluminum sulfate in the ration of animals receiving sodium fluoride was very effective in preventing fluorosis as indicated by metabolism trials.

Venkataramanan and Krishnaswamy (1948) reported that while some favorable results were obtained with calcium salts and vitamin C, the best ameliorating effects were obtained with aluminum salts. In this study teeth markings, bone storage of fluorine and weight gains in the albino rat were used as the criteria for measurement of the effectiveness of the aluminum salts.

Hobbs et al. (1950) reported that the amount of fluorine stored in the bone of the albino rat is directly proportional to the level of fluorine fed for a four and six week feeding period. This work indicated that four compounds $Al_2(SO_4)_3 \cdot 18\ H_2O$, sublimed $AlCl_3$, XH1010 (an aluminum compound containing 72.5% Al_2O_3), and Al (OH) $(C_2H_3O_2)_2$ reduced absorption of fluorine, as measured by bone storage, when added to rations at levels of 0.5, 1.0, and 2.0 per cent. In these tests it was found that once fluorine is deposited in the bone $Al_2(SO_4)_3 \cdot 18\ H_2O$, $AlCl_3$ (sublimed) or defluorophos did not increase removal of fluorine from the bone. The rate of fluorine turnover corresponded closely with the calcium and phosphorus rate of turnover. The lack of solubility of

$Al_2O_3.XH_2O$ and amberlite and the solubility of the other aluminum salts suggested the possibility that the alleviation effect may conceivably be tied up with the solubility of the resultant aluminum ion concentration.

Becker et al. (1950) reported on rats fed various levels of fluorine with the addition of aluminum sulfate ($18H_2O$), aluminum chloride and alumina to test their mitigating effect on chronic fluorosis. The fluorine content of the combined ash of their tibia and femur bones was used as an index of the degree of fluorine toxicosis. Their findings indicated that when these compounds were fed to supply equivalent quantities of aluminum, the chloride and the sulfate were of equal value for the alleviation of chronic fluorosis. On the same basis the alumina was less effective. When aluminum sulfate was fed at 0.53 per cent of the diet, the amount of fluorine in the bone ash showed a 45 per cent reduction. At lower levels of supplementation the aluminum sulfate was less effective.

Wadhwani (1952) observed that in monkeys vitamin C played an important ameloratic role in fluorine poisoning. In monkeys placed on a normal diet and receiving 10 mg. fluorine as sodium fluoride per kg. of body weight per day for six months, the daily administration of 20 mg. of vitamin C to each animal prevented fluorosis of the bones, as revealed by X-ray.

Griffith (1953) reported on lambs fed various levels of fluorine with alleviators. Alleviators used were aluminum sulfate hydrate and aluminum chloride hydrate added to a ration containing 100 ppm fluorine as sodium fluoride. The levels of these alleviators were 0.1 per cent

and 0.5 per cent aluminum sulfate hydrate and 0.1 per cent aluminum chloride hydrate.

It was reported that the addition of these alleviators had no material effect on feed consumption or weight gains. Metabolism trials indicated there were no appreciable effects in calcium, phosphorus or nitrogen balance studies or on the digestibility of crude fiber, crude protein, ether extract and nitrogen-free extract. It was noted that the lambs receiving alleviators excreted only about one-half as much urinary fluorine but three to four times as much fecal fluorine as lambs on the same level of fluorine with no alleviator added. Upon sacrificing these lambs Griffith reported that comparing lots at 100 ppm fluorine added with and without alleviators decreases in bone storage of 15 per cent, 35 per cent and 30 per cent for the 0.1 per cent aluminum sulfate hydrate, 0.5 per cent aluminum sulfate hydrate, and 0.1 per cent aluminum chloride hydrate groups respectively were obtained.

CHAPTER III

EXPERIMENTAL PROCEDURE

Cattle

The cattle used in this experiment were grade Hereford heifers purchased as yearlings in Texas in the summer of 1950. These animals were tested for tuberculosis and brucellosis before shipping and found negative for both. Prophylactic Brucella vaccine was administered to all animals after arrival. All animals were tattooed and later hip branded to insure positive identification. These animals were fed for approximately two weeks pre-experimental period in order to get them on feed and accustom them to individual feeding facilities. During this pre-experimental period the animals were fed two pounds of a concentrate mixture containing three parts ground yellow corn and one part cottonseed meal. Chopped mixed hay was fed and the amount gradually increased until the heifers were eating approximately thirteen pounds of hay at the time the experiment began. The initial experimental weight was approximately 641 pounds.

The heifers were allotted on basis of type grade, weight and condition into ten lots of three animals each. The animals were assigned to individual stanchions which were marked with the respective brand and lot number of each heifer. The animals were assigned to the stanchions in the barn by randomization in order to reduce the chances of position effects.

The concentrate mixture, consisting of three parts of number two ground yellow corn and one part forty-one per cent grade cottonseed meal, was mixed every two weeks. Fluorine in the form of sodium fluoride was added to the mixture to increase the fluorine content of the total ration to the desired levels. Feed consumption was observed closely and when there was any appreciable change in feed consumption the fluorine added was adjusted accordingly. The levels of fluorine added are shown in Table I. The sodium fluoride to be added to the concentrate mixture for each lot was weighed in the nutrition laboratory and put in a jar marked with the respective lot number. The sodium fluoride added to each batch of feed was first pre-mixed with a small amount of grain in a ten quart pyramid type laboratory pre-mixer prior to mixing with the bulk of the concentrate. Aluminum sulfate hydrate ($Al_2(SO_4)_3.18H_2O$) was added in the amounts as shown in Table I. The percentage added was based on total consumption and methods of weighing and mixing were the same as described for sodium fluoride. After thorough mixing the concentrate was drawn out of the mixer into tubs. The mixer was cleaned to prevent contamination of subsequent batches. The tubs containing concentrate for each lot were taken to a weighing table and weighed into paper bags. Each bag was marked with the appropriate lot number and contained the quantity for one day's feeding for one animal. The bags for each lot were then stored in separate marked containers. At the time of feeding the barn man would take three bags from each container and place them by the stanchions marked with lot numbers corresponding to the numbers marked on the bags.

TABLE I

PLAN OF CATTLE EXPERIMENT

Lot number	Treatment		Per cent NaF in total ration	Number of animals	Av. initial wt. (lbs.)
	ppm F added	Per cent $Al_2(SO_4)_3$ added[a]			
20A	0	0	0	3	647
20B	0	0.5%	0	3	653
21A	20	0	0.0044	3	665
21B	20	0.5%	0.0044	3	628
22A	30	0	0.0066	3	653
22B	30	0.5%	0.0066	2[b]	694
23A	40	0	0.0088	3	660
23B	40	0.5%	0.0088	3	651
24A	50	0	0.0110	3	656
24B	50	0.5%	0.0110	3	655

[a] $Al_2(SO_4)_3$ has $18H_2O$ attached.

[b] One animal in this lot was sacrificed 23 months after the experiment began.

Good quality mixed hay containing at least fifty per cent alfalfa was fed ad lib. The hay was chopped to promote uniform consumption and to facilitate easier weighing and feeding. The hay for each animal was weighed out into a burlap bag or large tub and placed in the stanchion before the animals were brought in the barn. The amount of hay fed was always two to three pounds in excess of consumption in order to promote maximum roughage consumption. The amount of hay offered was adjusted when necessary as determined from the feed records.

Hay samples were taken as the hay was fed to make a composite sample for analysis each month. A grain sample was taken from each batch after mixing and composite sample for a three month period secured for analysis. Each sample was analyzed for fluorine, moisture, crude protein, ether extract, crude fiber, nitrogen-free extract and ash. Results of these analyses for the three year period are shown below:

Per cent					
Moisture	Crude Protein	Ether Extract	Crude Fiber	Nitrogen-free extract	Ash
Hay					
7.8	9.5	1.5	36.0	39.5	5.9
Grain					
9.0	17.7	4.8	4.9	57.5	3.3

The animals were fed once daily, in the evening. After the animals were fastened in the stanchions the grain was poured in with

the hay. Animals remained in the stanchions all night and were turned out into dry lots in the morning with access to salt and water. After turning the cattle out refused portions of feed were recovered, weighed and recorded for the individual animals. For comfort of the animals this procedure was reversed during summer months. They were brought in the barn and fed in the morning and remained in the barn until evening when they were turned out in dry lots.

These heifers were bred as yearlings and therefore brought calves in the spring of 1951, 1952 and 1953. After calving the cow and calf were kept in a separate lot for two or three days. The cow was then returned to the barn for feeding and the calves nursed twice daily. The 1951 calves did not receive any feed in addition to their dams milk. However, the 1952 and 1953 calves were fed hay and a limited amount of concentrate.

The calves were weaned in November of each year. At this time they were approximately five months old. All the calves were slaughtered in 1951 and 1952 but none in 1953.

All animals were weighed periodically. From the time of eruption of the center pair of incisors the teeth (including molars and premolars) were examined for signs of the effects of fluorine at each weighing. Color photographs were also taken of the incisor teeth at this time.

The cattle were turned on pasture in the spring of 1953. They were on pasture from March 3, 1953 to September 4, 1953. The purpose of this was to check tooth wear under pasture conditions and also to provide more standard summer conditions for breeding and management.

At the time the cattle went on pasture they had been barn-fed and kept in dry lots exclusively for two and one-half years.

During this pasture phase the animals were brought into the barn in the morning and fed concentrate. The concentrate mixture was reduced to two pounds during this period. The same quantities of sodium fluoride and aluminum sulfate were added to this mixture as had been added to their previous rations of four pounds. Thus, the percentage of the additives in the two pounds of concentrate was doubled as compared to that of the four pounds of concentrate. No attempt was made to estimate the amount of grass consumed. The rate of addition of sodium fluoride and aluminum sulfate hydrate was the same throughout the pasture period as when the animals were taken off hay feeding. At this time the animals were consuming eighteen to nineteen pounds of hay daily.

The cattle were left in the barn two to three hours in the morning to allow sufficient time for all animals to consume their concentrate.

Metabolism trials were run on these cattle in the spring of 1952. Trials were also attempted in the spring of 1954. Considerable difficulty was encountered in getting the animals to consume normal amounts of feed while in the metabolism stalls. Complete cooperation of the animals in the 1952 test was not obtained. However, the data collected do give some interesting comparisons.

The equipment and methods of collection used for this trial were described by Hobbs et al. (1950A).

Seven day composite urine samples were collected for analysis. Ten per cent aliquots were taken daily to make seven day composite urine samples. All samples were corrected to a standard specific gravity of 1.040. All urine samples were analyzed for fluorine, calcium, phosphorus, and nitrogen.

Fecal aliquots were collected over a seven day period, using three per cent of the daily excretion for these aliquots and these in turn being used to form the seven day composite sample. These samples were analyzed for fluorine, calcium, phosphorus, nitrogen, ether extract, crude fiber, ash and moisture.

Bone samples of all the calves from animals in these lots were taken for fluorine analysis when they were sacrificed, slaughtered or died. The right metacarpal was always secured, and when possible the mandible and right ninth and tenth ribs were taken.

Rib resections were made on all cattle in these lots in July 1953. The twelfth rib on the left side was chosen for these resections because of ease of accessibility to the operator, and because of the location of the incision there would be less chance of contamination when the animal was lying down.

The animals were placed in a squeeze chute for the operation. Approximately one to one and one-half ounces of chloral hydrate was administered orally for mild sedation. An area was clipped from approximately the seventh rib anteriorly to the mid-point of the paralumbar fossa, and from the spine ventrally approximately twenty inches. This area was then scrubbed and an area approximately fifteen inches square was shaved. After scrubbing again antiseptic solutions were applied to the shaved and clipped area.

Approximately five to ten c.c. of two per cent procaine solution was deposited behind the eleventh, twelfth and thirteenth ribs, three to five inches below the costo-vertebral articulation, in an effort to block the inter-costal nerves. The site of incision was then infiltrated with the two per cent procaine solution. This was followed by deposition of two to three c.c. down to the periosteum in six to ten locations on the twelfth rib.

The primary incision was begun, dorsally, eight to ten inches from the costo-vertebral articulation, following the curviture of the rib, ventrally, six to seven inches. The secondary incision, through the muscle and periosteum to the bone, was five to six inches long. The periosteum was then stripped from the rib with the fingers. Obstetrical wire was then passed between the rib and the periosteum and a three to four inch section of the rib was removed. The muscle layers and the periosteum were sutured simultaneously with one continuous stitch using number three or four gut. The skin was then sutured with umbilical tape, using mattress type sutures. These sutures were removed twelve to fourteen days after the operation.

This procedure is somewhat similar to one described by Frank (1944) for a resection of the fifth rib.

The method used for the determination of fluorine in the various samples was a slight modification of the perchloric acid distillation and thorium nitrate titration method as described by Willard and Winter (1933). These modifications varied with the samples since the

materials included feeds, urine, feces, and bones. The fluorine content of feeds and feces was reported in ppm fluorine on an air-dry basis. Urine samples were reported in ppm fluorine on a volume basis. Bone analysis were reported in ppm fluorine on an ash basis.

Calcium and phosphorus determinations on feeds, feces, and urine were made according to the Association of Official Agricultural Chemists (1950) standards or slight modifications of these methods. Phosphorus was actually analyzed as P_2O_5 but in all tables it has been converted to phosphorus.

Proximate analyses of feeds and feces were determined by Association of Official Agricultural Chemists (1950) standard methods or slight modifications. These analyses included ash, moisture, crude protein, ether extract, crude fiber, and nitrogen-free extract which provided a basis for determining the digestibility of crude protein, crude fiber, ether extract, and nitrogen-free extract.

Sheep

Thirty-six western crossbred ewe lambs, eight to twelve months of age and averaging approximately eighty pounds in weight were used in this study. Wether lambs from the same source were used for individual feeding and metabolism studies by Griffith (1953). The lambs were carried through a pre-experimental period in an effort to rid them of internal parasites and get them on feed. During this period the daily ration of chopped hay and ground yellow corn was increased until the

animals were consuming approximately one and one-half pounds of hay and one-half pound of concentrate per head per day at the time the experiment began.

These lambs were allotted on the basis of weight, grade and condition into six lots with six animals per lot. Each animal was identified with a numbered ear tag and a paint brand. The first digit of the brand indicated lot number and the second the animal number, e.g., brand twenty-three on an animal indicated that it was in lot two and animal number three within that lot. These paint brands were renewed frequently as, through normal wear, they would become rather indistinguishable.

Each group was placed in a dry lot with free access to water and salt.

The rations consisted of chopped hay containing at least fifty per cent alfalfa fed ad lib. and one-half pound of number two ground yellow corn. The levels of fluorine and aluminum sulfate hydrate added are shown in Table II. The methods of calculating these additives and mixing the concentrates were the same as described for cattle. The ewes were group fed the grain and chopped hay once a day. Refused portions were collected, weighed, and recorded by lots daily.

These animals were weighed, their teeth examined, and color photographs made of the incisors.

These ewes lambed in 1951 and 1952; however, bone samples were obtained only from the 1952 lambs.

TABLE II

PLAN OF SHEEP EXPERIMENT

Lot No.	Treatment: ppm F added	Treatment: Per cent $Al_2(SO_4)_3$ added	Per cent in NaF total ration	Number of animals	Av. initial Wt. (lbs.)	Initial Wt. range (lbs.)
I	0	0	0	6	79.2	70 - 79
II	25	0	.0055	6	81.2	68 - 94
III	50	0	.0110	6	82.2	73 - 95
IV	50	0.2%	.0110	6	81.3	71 - 94
V	100	0	.0220	6	81.0	67 - 96
VI	100	0.4%	.0220	4[a]	84.2	73 - 104

[a]Only 4 animals in this lot.

This experiment was started at the University of Tennessee Middle Tennessee Experiment Station at Columbia, Tennessee, in December, 1949. In June 1951 the ewes were brought to the Knoxville Station where they were continued on test until the experiment was terminated in December 1952.

These animals were slaughtered in the University meats laboratory. All ewes were autopsied and bone samples were taken from the right metacarpal, mandible, and right ninth rib. Fluorine determinations were made on these samples.

Many procedures, such as methods of sampling hay and grain, feed adjustments, etc., not discussed in this section have been covered under the section on cattle.

CHAPTER IV

RESULTS AND DISCUSSION

Cattle

Feed Consumption

At the time the experiment was started the animals were consuming two pounds of concentrate mixture and approximately thirteen pounds of hay per day. Six months later their consumption of hay had increased to approximately sixteen pounds. The concentrate mixture was increased to three pounds at this time. One month later the concentrate was increased to four pounds per day. This increase in concentrate resulted in a temporary reduction in hay consumption of approximately one and one-half pounds.

The concentrate remained at the four pound level until the animals were put on pasture in the spring of 1953 when it was reduced to two pounds. This was done to insure complete consumption of the concentrate with alleviators while the animals were on pasture. When the animals were taken off pasture in the fall they were returned to the ad lib. hay and four pound concentrate ration. This ration was continued.

Table III shows the average daily feed consumption by years and the overall average daily consumption for the three year period. It can be noted from this table that the average daily consumption of hay was slightly higher in the groups receiving aluminum sulfate hydrate,

TABLE III

AVERAGE DAILY FEED CONSUMPTION OF CATTLE FED VARIOUS LEVELS OF FLUORINE AND ALUMINUM SULFATE

Lot Number	1951		1952		1953		1951-1953	
	Hay	Conc.	Hay	Conc.	Hay	Conc.	Hay	Conc.
20A	15.17	3.11	15.48	3.98	18.92	2.68	16.06	3.27
20B	15.40	3.11	15.81	3.96	18.80	2.48	16.26	3.20
21A	14.30	3.11	14.87	3.97	18.33	2.70	15.36	3.27
21B	14.54	3.10	15.35	3.97	18.43	2.39	15.66	3.17
22A	13.92	3.11	15.16	3.95	18.68	2.65	15.39	3.25
22B[a]	15.86	3.10	16.11	3.99	18.96	2.40	16.60	3.18
23A	15.81	3.10	16.12	3.99	18.96	2.60	16.50	3.24
23B	14.19	3.05	15.22	3.97	18.68	2.45	15.52	3.18
24A	13.86	3.11	14.12	3.99	17.43	2.60	14.70	3.25
24B	15.53	3.10	16.23	3.99	19.14	2.40	16.60	3.22

[a]Only 2 animals in this lot.

except in the case of lot 23B where the reverse was true. This table also shows that the groups receiving no aluminum sulfate hydrate in their ration consumed slightly more grain than did the groups receiving this compound in their ration. There were no significant differences between lots in feed consumption.

The average fluorine content of the hay fed these animals was 4.6 ppm (range 2 to 9 ppm F), and the concentrate for the control ration contained an average of 24.5 ppm (range 7 to 65 ppm F) (one sample of 65 ppm was apparently out of line).

The average daily ingestion of fluorine and aluminum sulfate hydrate of these animals is shown in Table XVII. These figures are reported in milligrams of fluorine and aluminum sulfate hydrate per kilogram of body weight. Under the conditions of this experiment these data would indicate that the level of fluorine and/or the addition of aluminum sulfate hydrate to the rations had no effect on feed consumption.

Weight Gains

The average initial weight of the individual lots ranged from 628 pounds to 694 pounds. There was considerable variation within some lots. Table I shows the average beginning weight and Table IV shows the average daily gain by years and the overall average daily gain. There were no statistically significant differences in the average daily gains between lots.

This would indicate that, under the conditions of this experiment, the addition of sodium fluoride and/or aluminum sulfate had no appreciable

TABLE IV

AVERAGE DAILY GAINS OF CATTLE FED VARIOUS LEVELS OF FLUORINE AND ALUMINUM SULFATE

Lot No.	Treatment: ppm F added	Treatment: Per cent $Al_2(SO_4)_3$ added	1951 (377 days)	1952 (368 days)	1953 (342 days)	1951-1953 (1087 days)
20A	0	0	.62	.38	.42	.48
20B	0	0.5	.56	.39	.31	.42
21A	20	0	.50	.36	.44	.43
21B	20	0.5	.41	.38	.40	.40
22A	30	0	.49	.33	.21	.35
22B[a]	30	0.5	.41	.38	.37	.39
23A	40	0	.55	.58	.20	.45
23B	40	0.5	.50	.27	.28	.35
24A	50	0	.48	.48	.28	.41
24B	50	0.5	.76	.26	.49	.51

[a]Only 2 animals in this lot.

affect on weight gains for the period studied.

Digestibility

Metabolism trials were run on the cattle in the spring of 1952. At this time the animals had been on experiment approximately eighteen months. A summary of the average percentage apparent digestibility for crude protein, crude fiber, ether extract, and nitrogen-free extract for these cattle is shown in Table V. There was some variation in the apparent digestibility figures for the various nutrients.

Balance Studies

Fluorine Balance. The average daily fluorine balance for all animals subjected to, and collected from, metabolism trials is shown in Table VI. In general the milligrams of fluorine ingested followed the amount of fluorine added to the ration. Differences that do occur might logically be attributed to small numbers of animals, variation in feed consumption, sampling errors, and chemical determination errors.

In general the fluorine excreted in the urine increased as the level of fluorine increased where comparing non-alleviator (A) groups and alleviator (B) groups separately. The urinary fluorine was appreciably reduced and the fecal fluorine was increased in lots where aluminum sulfate hydrate was added, when compared to lots on corresponding levels of fluorine intake without the addition of this compound. This might tend to substantiate postulations by Sharpless (1936), Majumdar and Ray (1946) and Griffith (1953) that the aluminum sulfate hydrate "ties up" the fluorine in the gastro-intestinal tract.

TABLE V

AVERAGE APPARENT DIGESTION COEFFICIENTS FOR CATTLE FED VARIOUS LEVELS OF FLUORINE AND ALUMINUM SULFATE

Lot No.	Treatment: ppm F added	Treatment: Per cent $Al_2(SO_4)_3$ added	Number of animals	Percentage apparent digestibility: Dry matter	Crude protein	Ether extract	Crude fiber	Nitrogen-free extract
20A	0	0	2	63.4	65.5	47.6	51.4	74.0
20B	0	0.5	2	63.6	63.6	56.3	50.6	74.7
21A	20	0	3	64.2	62.5	47.5	54.4	73.3
21B	20	0.5	2	62.8	58.4	49.4	52.8	72.3
22A	30	0	1	64.2	65.4	62.8	56.5	71.2
22B	30	0.5	3	62.2	61.6	55.0	52.6	72.0
23A	40	0	3	62.9	62.4	54.1	58.2	73.7
23B	40	0.5	2	65.1	61.4	59.0	59.0	74.1
24A	50	0	2	66.2	61.7	50.8	58.2	75.2
24B	50	0.5	3	64.5	64.7	56.6	54.9	74.6

TABLE VI

AVERAGE DAILY FLUORINE BALANCE OF CATTLE FED VARIOUS LEVELS OF FLUORINE AND ALUMINUM SULFATE

Lot No.	Treatment		Number of animals[a]	Fluorine - Milligrams					Per cent fluorine excreted in feces
	ppm F added	Per cent $Al_2(SO_4)_3$ added		Intake	Urine	Feces	Retained	Per cent Retained	
20A	0	0	2	56.6	27.8	27.4	1.4	2.5	49.6
20B	0	0.5	2	56.2	16.2	27.1	13.0	23.1	62.7
21A	20	0	3	216.2	79.3	55.0	81.9	37.9	41.0
21B	20	0.5	2	223.4	44.8	119.4	59.2	26.5	72.7
22A	30	0	1	301.6	198.4	66.7	36.5	12.1	25.2
22B	30	0.5	3	324.3	54.2	159.4	110.7	34.1	74.6
23A	40	0	3	415.7	109.0	71.5	235.3	56.6	39.6
23B	40	0.5	2	320.2	69.3	177.4	73.6	23.0	71.9
24A	50	0	2	437.9	99.7	122.5	215.7	49.2	55.1
24B	50	0.5	3	507.9	87.5	214.1	206.3	40.6	71.0

[a]Each animal was on collection test period for 7 days.

Table XVIII gives the figures for individual animals. These figures will demonstrate the variation in these results and explain some of the irregularities that are shown in Table VI.

The reductions in the percentage fluorine retained in some of the lots receiving aluminum sulfate hydrate, might tend to explain the corresponding reductions in bone deposition in these alleviator groups as presented in Table IX.

Calcium, Phosphorus and Nitrogen Balances. Balances of these minerals, for the animals run, are presented in Table VII. As in the case of digestibility of nutrients these figures vary considerably and do not seem to follow any definite pattern with reference to the different rations. There was apparently no appreciable difference.

Reproduction

Cows in these lots calved in 1951, 1952, and 1953. Table VIII shows a yearly and overall summary of the number of calves born, average birth weight, average daily gain, and overall number of calves weaned. There were no significant differences between lots in birth weights or average daily gains. It appears also, that the number of calves born or raised in the various lots was not influenced by the rations the animals were on.

The calf crop in 1951 was 69 per cent, in 1952 86 per cent, and in 1953 41 per cent - based on the number of calves born. As previously stated these cattle were turned out on pasture in the spring of 1952, in an effort to increase the rate of conception.

TABLE VII

AVERAGE DAILY BALANCE OF CALCIUM, PHOSPHORUS AND NITROGEN FOR CATTIE FED VARIOUS LEVELS OF FLUORINE AND ALUMINUM SULFATE

Lot No.	Treatment		Number of animals[a]	Grams		
	ppm F added	Per cent $Al_2(SO_4)_3$ added		Calcium	Phosphorus	Nitrogen
20A	0	0	2	-1.7	- .9	1.5
20B	0	0.5	2	-2.1	-4.6	1.0
21A	20	0	3	-1.6	-5.8	-6.5
21B	20	0.5	2	2.6	.3	4.7
22A	30	0	1	-2.8	.9	14.2
22B	30	0.5	3	-5.8	- .1	4.6
23A	40	0	3	-6.8	1.6	-5.2
23B	40	0.5	2	-2.2	-13.0	- .4
24A	50	0	2	-6.4	.4	-10.6
24B	50	0.5	3	-1.0	-7.5	.4

[a]Each animal was on collection test period for 7 days.

TABLE VIII

SUMMARY OF AVERAGE DAILY GAINS AND BIRTH WEIGHTS OF CALVES PRODUCED BY COWS FED VARIOUS LEVELS OF FLUORINE AND ALUMINUM SULFATE[a]

Lot number	1951 Number born	1951 Average birth weight[b]	1951 Average daily gain	1952 Number born	1952 Average birth weight[b]	1952 Average daily gain	1953 Number born	1953 Average birth weight[b]	1953 Average daily gain	1951 - 1953 Number born	1951 - 1953 Number weaned	1951 - 1953 Average birth weight[b]	1951 - 1953 Average daily gain
20A	1	66	1.32	2	54	1.35	0	-	-	3	2	57.7	1.34
20B	3	52	1.67	3	54	1.65	2	67	1.45	8	7	55.7	1.60
21A	2	57	1.40	2	57	1.61	1	52	1.22	5	4	55.7	1.41
21B	3	55	1.27	3	53	1.62	0	-	-	6	4	53.8	1.45
22A	1	60	1.62	3	56	1.68	2	68	1.74	6	5	61.4	1.69
22B[c]	2	53	1.75	2	55	1.57	1	-	-	5	4	53.8	1.66
23A	3	61	1.59	2	56	1.50	1	60	1.52	6	5	57.4	1.56
23B	2	49	1.48	3	57	1.32	3	64	1.38	8	8	57.9	1.38
24A	2	51	1.35	1	-	-	1	67	1.69	4	3	58.3	1.46
24B	1	58	1.66	3	55	1.61	1	51	1.62	5	5	54.8	1.62

[a]Average daily gains were adjusted for differences in age, sex and years.

[b]Birth weights of calves that died were used when available.

[c]Only 2 cows in this lot.

At the present time (April, 1954) all the cows have not calved. The number of calves already born (16) and the number of cows found by rectal palpation to be pregnant (11), leaves only two animals either without a calf or not pregnant. One of these two animals aborted some months ago. Considering that only one animal in the entire group failed to conceive, the number of calves born in 1954 should be twenty-eight. This would give a calf crop of 96 per cent calves born (including the aborted fetus as a calf born).

Fluorine Content of Bones

Since these animals are being continued on experiment, chemical analysis for fluorine storage in the bone is limited to one analysis from each animal. The source of this analysis is the rib resections made in 1953. At this time the animals had been on the various rations for approximately 38 months. Results of these analyses are shown in Table IX.

As shown in this table, the fluorine content of the left twelfth rib, was significantly reduced by the addition of 0.5 per cent aluminum sulfate hydrate to rations that had 30, 40 and 50 ppm fluorine added (lots 22B, 23B and 24B, respectively) when compared to rib analyses from animals fed comparable levels of fluorine with no aluminum sulfate hydrate added (lots 22A, 23A, and 24A, respectively). This reduction in fluorine storage was also evident at the 20 ppm level in the group receiving aluminum sulfate hydrate (lot 21B) when compared to the group receiving the same level of fluorine without aluminum sulfate hydrate (lot 21A). However, the amount of reduction in this case was not significant, as measured by the "t test" described by Snedecor (1950).

It can be noted that the average fluorine content of the ribs in lot 24B (50 ppm F +0.5% $Al_2(SO_4)_3$ added) is slightly lower than the average fluorine content of the ribs in lot 22A (30 ppm F added). Also, the average for lot 23B (40 ppm F + 0.5% $Al_2(SO_4)_3$ added) approximates the analysis of lot 21A (20 ppm F added).

The 1951 and 1952 calves were slaughtered and bone samples taken. The 1953 calves were not slaughtered at weaning time; therefore, there are no analyses reported for that year. Samples from the metacarpal and mandible were obtained from the 1951 calves, but only from the metacarpal in 1952.

The metacarpal sample was taken from the medial proximal quarter of the right metacarpal. The mandible sample was obtained from the angle of the right mandible.

The 1951 calves received no feed in addition to their dams milk. The 1952 calves were fed hay ad lib. and a limited amount of concentrate similar to the mixture fed the cows (no fluorine added).

The results of the average analyses of these bones are shown in Table X. Since there was a remarkable difference in analyses between years, these results are shown separately. The calves slaughtered in 1951 averaged 55 days older than the 1952 calves.

Because of the small numbers and within lot variation so great, these data would be difficult to interpret. It would appear from these analyses that the addition of fluorine and/or aluminum sulfate hydrate to the rations of these cows had no appreciable effect on the fluorine content of bones from calves produced by these cows.

TABLE IX

FLUORINE CONTENT OF RIBS OF COWS FED VARIOUS LEVELS OF FLUORINE AND ALUMINUM SULFATE[a]

Lot number	ppm F added	Per cent $Al_2(SO_4)_3$ added	Animal number	ppm F in ribs	Average ppm F in ribs	Reduction (in ppm)	Per cent reduction
			100	800			
20A	0	0	101	600	667		
			102	600			
						0	0
			103	600			
20B	0	0.5	104	700	667		
			105	700			
			106	2900			
21A	20	0	107	1800	2267		
			108	2100			
						467	20.6
			109	1800			
21B	20	0.5	110	1500	1800		
			111	2100			
			119	3200			
22A	30	0	113	3000	3267		
			114	3600			
						1167*	35.7
			112	2100			
22B	30	0.5	117	2100	2100		
			118	3900			
23A	40	0	115	3900	4000		
			120	4200			
						1667**	41.7
			121	2100			
23B	40	0.5	125	2400	2333		
			123	2500			
			124	4400			
24A	50	0	122	5200	4967		
			126	5300			
						1867*	37.6
			127	2400			
24B	50	0.5	128	3200	3100		
			129	3700			

a From rib resections

*$P < 0.05$

**$P < 0.01$

TABLE X

FLUORINE CONTENT OF CALF BONES PRODUCED BY COWS FED VARIOUS LEVELS OF FLUORINE AND ALUMINUM SULFATE

Lot Number	1951			1952	
	Number of analyses	Average ppm F in mandible	Average ppm F in metacarpal	Number of analyses	Average ppm F in metacarpal
20A	1	110	120	1	134
20B	2	245	205	3	94
21A	2	230	210	1	167
21B	2	185	185	2	90
22A	1	250	220	2	140
22B	2	190	185	2	114
23A	3	193	217	1	152
23B	2	150	175	3	134
24A	2	150	185	0	-
24B	1	210	240	3	138

Teeth Examinations

Many investigators report that teeth lesions due to abnormally increased levels of fluorine may be used as a partial index in determining the extent of damage by this element.

Detailed teeth examinations were made monthly or bimonthly which included detailed descriptions and color photographs. Some form of classification was needed in order to compare the teeth of animals on various levels of fluorine. A classification chart was devised by Hobbs et al. (1953), a reproduction of which is presented in Table XIX.

In order to present some data on the effect aluminum sulfate hydrate might have on reducing tooth lesions by increased levels of fluorine, Table XI is included to give a record of the current classification of the incisors of all cattle in this experiment. The markings are usually bilateral, but in cases where this is not true the right tooth of the pair is given below the classification for the left tooth.

Wear is also ascertained and recorded for the individual teeth. This recording is also done by classification. The method for recording wear is as follows:

a - Uneven

A - Normal for age and general conditions

B - Slight

C - Medium

D - Heavy

E - Excessive

TABLE XI

COMPARISON OF CURRENT TEETH CLASSIFICATIONS OF CATTLE FED VARIOUS LEVELS OF FLUORINE, WITH AND WITHOUT THE ADDITION OF ALUMINUM SULFATE

Lot No.	An. No.	1st C[a]	Pr. W[b]	2nd C	Pr. W	3rd C	Pr. W	4th C	Pr. W	ppm F added	1st C	Pr. W	2nd C	Pr. W	3rd C	Pr. W	4th C	Pr. W	An. No.	Lot No.
	100	1A	A	1A	A	1A	A	1A	A		1A	Ba	1A	A	1A	A	1A	A	103	
20A	101	1A	A	1A	A	1A	A	1A	A	0	1A	A	1A	A	1A	A	1A	A	104	20B
	102	1A	A	2	A	2	A	1A	A		1A	A	1A	A	1A	A	1A	A	105	
	106	1A	A	2	A	4	A	2	A		1A	A	2	Ba	1B	A	3	A	109	
						2	A													
21A	107	1A	A	2	A	2	Ba	2	A	20	2	B-C	1B	Ba	3	A-B	2	A	110	21B
	108		c	1B	A	2	A	2	A		1A	Ba	1BX	B-D	2	A	2	A	111	
													1BX	B-C						
	113	1B	A	2	A	2	A	2	A		1A	A	1A	A	2	A	2	A	112	
											1A	B	1B	A						
22A	114	1A	A	3	Ba	4	A	4	B	30	1A	A	1A	A	2	A	2	A	117	22B[e]
				2	Ba	3	A	3	A											
	119	1A	A	2	A	2	A	2	A											
				3	A	3	A													

[a] C refers to classification of tooth - see Table XIX.

[b] W refers to amount of wear.

[c] Teeth mechanically cracked out.

[d] Mechanically chipped - cannot classify as to wear.

[e] Only 2 animals in this lot.

TABLE XI

COMPARISON OF CURRENT TEETH CLASSIFICATIONS OF CATTLE FED VARIOUS LEVELS OF FLUORINE, WITH AND WITHOUT THE ADDITION OF ALUMINUM SULFATE (continued)

Lot No.	An. No.	1st Pr. C[a]	1st Pr. W[b]	2nd Pr. C	2nd Pr. W	3rd Pr. C	3rd Pr. W	4th Pr. C	4th Pr. W	ppm F added	1st Pr. C	1st Pr. W	2nd Pr. C	2nd Pr. W	3rd Pr. C	3rd Pr. W	4th Pr. C	4th Pr. W	An. No.	Lot No.
	118	1B	A	2	B	4	B	5A	B		1A	A	1A	A	2	A	2	A	121	
				2	C															
23A	115	1A	A	2	A	5A	B	5A	B	40	1A	A	1B	A	2	A	2	A	125	23B
	120	1A	A	2	A	4	C	2	B		1A	A	1B	A	2	A	2	A	123	
								3	B											
	122	1B	B	2	C	4	B	5A	B-C		1A	A	2	A	4	A	4	A	127	
		1B	A	2	A										4X	d	4X	d		
24A	124	1A	A	2	Ba	4	B	4	B	50	1A	A	1A	A	3	A	2	A	128	24B
	126	1B	B	3	B	5A	C	5C	D		1A	A	3A	A	2	B	2	B	129	
													2B	A			3	B		

[a]C refers to classification of tooth - see Table XIX.

[b]W refers to amount of wear.

[c]Teeth mechanically cracked out.

[d]Mechanically chipped - cannot classify as to wear.

[e]Only 2 animals in this lot.

A close study of the classification of the incisors of animals in the aluminum sulfate hydrate fed (B) groups shows that this compound did decrease teeth lesions. This is most noticeable when comparing lot 23B to lot 23A.

This experiment combined with other experiments shows that the teeth are one good criterion to use along with others in determining the amount of fluorine being ingested at the time of development of a specific tooth.

Sheep

Feed Consumption

At the time this experiment was initiated the animals were consuming approximately one and one-half pounds of hay and one-half pound of concentrate. During 1952 the average daily feed consumption, as shown in Table XII, increased from one and one-half pounds to approximately three pounds of hay. Since the lambs were in the lots with the ewes, they consumed some of the same feed as the ewes in the respective lots.

During the first two years there was practically no difference in hay or concentrate consumption between any of the lots. In 1952, however, there was a reduction in the hay consumption in lot six.

The average fluorine content of the hay fed these animals was 9.9 ppm (range 4 to 38 ppm F) and the concentrate for the control group averaged 17 ppm F (only three analyses with a range of 8 to 31 ppm F).

TABLE XII

AVERAGE DAILY FEED CONSUMPTION OF SHEEP FED VARIOUS LEVELS OF FLUORINE AND ALUMINUM SULFATE

Lot number	Treatment		1950		1951		1952		1950 through 1953	
	ppm F added	Per cent $Al_2(SO_4)_3$ added	Hay	Concentrate	Hay	Concentrate	Hay	Concentrate	Hay	Concentrate
I	0	0	1.98	.49	2.98	.50	2.98	.50	2.66	.50
II	25	0	1.94	.49	2.98	.50	2.97	.50	2.64	.50
III	50	0	1.93	.49	2.98	.50	2.97	.50	2.64	.50
IV	50	0.2%	1.96	.48	2.98	.50	2.97	.50	2.65	.50
V	100	0	1.95	.48	2.98	.50	2.91	.50	2.63	.50
VI[a]	100	0.4%	2.06	.52	2.99	.50	2.52	.47	2.52	.50

[a]Only 4 animals.

The average daily milligrams per kilogram of body weight of fluorine and aluminum sulfate hydrate of these animals is shown in Table XX.

The level of fluorine fed had no apparent effect upon feed consumption. At the 50 ppm level (lots III and IV) the addition of 0.2 per cent aluminum sulfate had no effect on feed consumption when compared to the ration void of this compound. Lot VI, 100 ppm fluorine and 0.4 per cent aluminum sulfate hydrate, consumed less feed than any of the other lots in 1952. Griffith (1953) reported no significant differences in feed consumption of wether lambs on a ration similar to lot VI when compared to rations identical to lots I, II and III of this experiment.

Weight Gains

The average daily gains of the sheep are reported in Table XIII. Table II shows the average initial weight and range by lots. All lots showed weight losses for the year of 1952. This might be partially attributed to the fact that the ewes were nursing lambs and the lambs were competing with the ewes for feed.

The results of the weight gains of the ewes paralled the findings on the cattle. Griffith (1953) also substantiated this by reporting no material effect on weight gains with wether lambs fed similar rations for a 140-day period.

Reproduction

The ewes used in this experiment lambed in 1951 and 1952. The ewes were at the Middle Tennessee Experiment Station at Columbia, Tennessee when the ewes lambed in 1951. The lambing data available

TABLE XIII

AVERAGE DAILY GAINS OF SHEEP FED VARIOUS LEVELS OF FLUORINE AND ALUMINUM SULFATE

Lot number	Treatment: ppm F added	Treatment: Per cent $Al_2(SO_4)_3$ added	1950 (344 days)	1951 (352 days)	1952 (387 days)	1950-1952 (1083 days)
I	0	0	.10	.04	-.01	.04
II	25	0	.10	.07	-.06	.04
III	50	0	.01	.05	-.04	.03
IV	50	0	.11	.02	-.00	.04
V	100	0.2	.11	.04	-.06	.03
VI[a]	100	0.4	.14	.00	-.00	.04

[a]Only 4 animals in this lot.

for 1951 show only the birth weights of the lambs. There were no significant differences between lots in the birth weights of the lambs produced in both years and no differences between lots in average daily gain in the 1952 lambs. The level of fluorine apparently did not reduce the number of lambs born since lot V had 92 per cent lamb crop and lot VI had 88 per cent lamb crop for the two years. The average of all lots for the two years was 68 per cent.

The summary of the birth weights for 1951 and 1952 and the average daily gains of these lambs is shown in Table XIV.

Fluorine Content of Bones

Results of the average analyses of samples from the metacarpals, mandibles and ninth ribs of these ewes are shown in Table XV. The metacarpal and mandible samples were taken in the same manner as for the calves. The rib sample was obtained from the distal half of the right ninth rib. Individual analyses can be found in Table XXI.

The addition of 0.2 per cent aluminum sulfate hydrate significantly reduced the fluorine storage in the ribs of these sheep at the 50 ppm fluorine level (lot III compared to lot IV). Significant reductions were also obtained when 0.4 per cent aluminum sulfate hydrate was added to the ration of ewes fed fluorine at the 100 ppm level (lot V compared to lot VI). The average fluorine content of the rib analysis of lot VI (100 ppm F + 0.4% $Al_2(SO_4)_3$ added) was almost as low as the average fluorine content of the rib analysis of lot III (50 ppm F added).

TABLE XIV

SUMMARY OF AVERAGE DAILY GAINS AND BIRTH WEIGHTS OF LAMBS PRODUCED BY EWES FED VARIOUS LEVELS OF FLUORINE AND ALUMINUM SULFATE[a]

	1951		1952		
Lot number	Number born	Average birth weight	Number born	Average birth weight	Average daily gain
I	5	7.2	2	7.9	.32
II	2	8.3	4	9.4	.44
III	4	7.3	4	10.6	.37
IV	5	9.2	2	10.4	.28
V	5	6.7	6	8.2	.38
VI[b]	4	7.8	3	8.2	.33

[a]Average daily gains available only on 1952 lambs.

[b]Only 4 ewes in this lot.

Fluorine storage in the mandibles was significantly reduced at the 50 ppm fluorine added level by the addition of 0.2 per cent aluminum sulfate hydrate when compared to the ration that contained no aluminum sulfate hydrate (lot III). It should also be noted that the addition of 0.4 per cent aluminum sulfate hydrate to a ration containing 100 ppm fluorine added (lot VI) produced a high percentage decrease in fluorine content of the mandibles when compared to a ration containing the same amount of fluorine but no aluminum sulfate hydrate (lot V).

No significant reductions in the fluorine content of the metacarpal were observed. It should be noted, however, that the average analyses of the metacarpals of lot VI (100 ppm F + 0.4% $Al_2(SO_4)_3$ added) is practically the same as that of lot III (50 ppm F added).

These data would indicate that under the conditions of this experiment 0.2 per cent aluminum sulfate hydrate significantly reduced the fluorine storage in the right ninth rib and mandible of ewes receiving a ration with 50 ppm fluorine added over a three year period. Also, significant reductions in fluorine storage in the right ninth rib were obtained by the addition of 0.4 per cent aluminum sulfate hydrate to a ration that had 100 ppm fluorine added. High percentages of reduction in fluorine content were shown in the mandibles and metacarpals.

The results of analyses of the right metacarpals of the lambs produced from the ewes in lots I through VI in 1952 are shown in Table XVI. Since these lambs were kept in the same lots as the ewes, they consumed some of the feed. Thus the increases in the amount of fluorine in the metacarpals of these lambs parallels the increases in the rate of fluorine added to the rations of the various lots.

TABLE XV

AVERAGE FLUORINE CONTENT OF BONES FROM SHEEP FED VARIOUS LEVELS OF FLUORINE AND ALUMINUM SULFATE[a]

Lot number	ppm F in metacarpal	Reduction in ppm F	Per cent Reduction	ppm F in mandible	Reduction in ppm F	Per cent reduction	ppm F in rib	Reduction in ppm F	Per cent reduction
I	937			1317			1300[b]		
II	2733			5233			5400		
III	4367	617	9.6	8733	1166*	13.3	9480[c]	2930**	30.9
IV	3950			7567			6550[d]		
V	9717	5342	44.7	12000	2940	22.7	12740[c]	3310**	23.7
VI	4375[d]			9060[d]			9430[d]		

[a]Individual analysis reported in Table XXI.

[b]One analysis of 8300 ppm F was not included in this average.

[c]Only 5 analyses.

[d]Only 4 analyses.

*$P < 0.05$

**$P < 0.01$

TABLE XVI

FLUORINE CONTENT OF LAMB METACARPAL BONES FROM EWES FED VARIOUS LEVELS OF FLUORINE AND ALUMINUM SULFATE[a]
1952

Lot I	Lot II	Lot III	Lot IV	Lot V	Lot VI
213	236	540	480	980	945
130	270	640	715	850	970
	385	520		1020	1035
	305	610		1050	
				1440	
				1050	
Av.172	299	578	598	1065	1026

[a]Analyses are in ppm F.

CHAPTER V

SUMMARY

The possible alleviation effects of aluminum sulfate hydrate were studied over a three-year period in twenty-nine cattle and thirty-four sheep. In the cattle experiment 0.5 per cent aluminum sulfate hydrate was added to rations with 0, 20, 30, 40 and 50 ppm fluorine added. This experiment is still in progress. In the sheep experiment fluorine was added at the rate of 0, 25, 50 and 100 ppm with 0.2 per cent aluminum sulfate hydrate being added to a ration with 50 ppm fluorine and 0.4 per cent aluminum sulfate hydrate added to a ration containing 100 ppm fluorine.

These data show that under the conditions of these experiments there were no appreciable differences in feed consumption or weight gains in the cattle and sheep that could be associated with the various treatments.

Apparent digestibility coefficients for the various nutrients varied considerably. This made it difficult to associate any differences in apparent digestibility of crude protein, ether extract, nitrogen-free extract and crude fiber with the addition of fluorine or aluminum sulfate hydrate to the rations of cattle. Mineral balance studies indicated that generally, the addition of aluminum sulfate hydrate to rations to which fluorine was added decreased the amount of

fluorine retained and also increased the percentage of fluorine excreted in the feces. As in the case of the various nutrients, there were no appreciable differences between lots in retention of calcium, phosphorus, or nitrogen.

These data would indicate that under the conditions of these experiments there were no differences in the number born, birth weights or average daily gains in the calves and lambs which could be attributed to different treatments of their dams.

The fluorine content of the calf bones did not seem to be associated with the different treatments of their dams. Since the lambs were kept with the ewes they consumed some of the feed; therefore, the fluorine content of their metacarpals increased relatively with the amount of fluorine added to the different lots.

The fluorine content of the ribs of the cattle was significantly decreased by the addition of 0.5 per cent aluminum sulfate hydrate at the 30, 40 and 50 ppm fluorine added levels. The addition of 0.2 per cent aluminum sulfate hydrate to the ration of sheep on 50 ppm fluorine significantly reduced fluorine storage in the ribs and mandibles. When 0.4 per cent aluminum sulfate was added to the ration of sheep receiving 100 ppm fluorine the fluorine content of the rib was reduced significantly.

BIBLIOGRAPHY

BIBLIOGRAPHY

Agate, J. N., G. H. Bell, G. F. Boodie, R. G. Bowler, M. Buckwell, E. A. Cheeseman, T. H. Douglas, H. A. Druett, J. Garrad, D. Hunter, K. M. A. Perry, J. D. Richman and J. B. de V. Weir. 1949. Industrial Fluorosis. Med. Res. Council Memo. No. 22. London H. M. Stationery Off.

Association of Official Agricultural Chemists. 1950. Official Methods of Analysis, 7th Edition.

Bauer, W. H. 1945. Experimental Chronic Fluorine Intoxication. Effect on Bones and Teeth. Am. Jour. Orthodontics, Oral Surg. 31:700-719.

Becker, D. E., J. M. Griffith, C. S. Hobbs and W. H. MacIntire. 1950. The Alleviation of Fluorine Toxicosis by Means of Certain Aluminum Compounds.(Abstract) Jour. Animal Sci. 9:647.

Blakemore, F., T. J. Bosworth and H. H. Green. 1948. Industrial Fluorosis of Farm Animals in England, Attributable to the Manufacture of Bricks, The Calciming of Ironstone and to Enameling Processes. Jour. Comp. Path. and Therap. 58:267-301.

Frank, E. R. 1944. Veterinary Surgery Notes. Burgess Publishing Co. Minneapolis, Minn. 161-162.

Griffith, J. M. 1953. Certain Physiological and Pathological Effects of Feeding Various Levels of Fluorine and Alleviators to Lambs. Master's of Science Thesis. Univ. of Tenn.

Hobbs, C. S., E. R. Barrick, D. E. Becker, J. A. Ewing, J. M. Griffith, R. P. Moorman, Dennis Sikes, J. L. West, E. J. Chapman and James McLaren. 1950. The Effects of Certain Atmospheric Effluents Upon the Growth and Composition of Plants Upon Animal Life at Locals in East and Central Tennessee. Annual Report Tenn. Agr. Exp. Sta.

Hobbs, C. S., Sam L. Hansard, and E. R. Barrick. 1950A. Simplified Methods and Equipment Used in Separation of Urine from Feces Eliminated by Heifers and by Steers. Jour. Animal Sci. 9:565-570.

Hobbs, C. S., P. H. Phillips, D. A. Greenwood, R. P. Moorman, G. M. Merriman and J. M. Griffith. 1953. Classification of the Effects of Dietary Fluorine on Teeth of Cattle. Unpublished data, Univ. of Tenn., Univ. of Wis., and Utah State College.

Marcovitch, S. and W. W. Stanley. 1942. Study of Antidotes for Fluorine. Jour. Pharm. and Exp. Therap. 74:235-328.

Majumdar, B. N., S. N. Ray and K. C. Sen. 1943. Fluorine Intoxication of Cattle in India. Indian Jour. Vet. Sci. 13:95-107.

Majumdar, B. N. and S. N. Ray. 1946. Fluorine Intoxication of Cattle in India. II. Effect of Fluorosis on Mineral Metabolism. Indian Jour. Vet. Sci. 16:107-112.

Maynard, L. A. 1947. Animal Nutrition. 3rd Ed. McGraw-Hill Book Co., Inc.

McClure, E. J. 1933. A Review of Fluorine and the Physiological Effects. Physiol. Rev. 13:277-300.

Mitchell, H. H. and Marjorie Edman. 1952. The Fluorine Problem in Livestock Feeding. Nutr. Abstr. Rev. 21:787-804.

Roholm, Kaj. 1937. Fluorine Intoxication, A Clinical Hygiene Study with a Review of the Literature and Some Experimental Investigations. H. K. Lewis and Co., London, England.

Schmidt, H. J. and W. H. Rand. 1952. A Critical Study of the Literature on Fluoride Toxicology with Respect to Cattle Damage. American Jour. of Vet. Res. No. 46. 13:38-49.

Sharpless, George R. 1936. Limitation of Fluorine Toxicosis in the Rat with Aluminum Chloride. Proc. Soc. Exp. Biol. and Med. 34:562-564.

Snedecor, George W. 1946. Statistical Methods. Fourth Edition. Iowa State College Press, Ames, Iowa.

Venkatarmanan, K. and N. Krishnaswamy. 1948. The Amelioration of Symptoms of Fluorosis by Aluminum Salts. Indian Jour. Med. Res. 37:277-282.

Wadhwani, T. K. 1952. Mitigation of Fluorosis (Experimental) Part I. Indian Med. Gaz. Jan. pp. 5-7.

Willard, H. H. and O. B. Winter. 1933. Volumetric Methods for Determination of Fluorine. Ind. Eng. Chem. Analytical Edition. 5:7.

APPENDIX

CRANES CREST

TABLE XVII

AVERAGE DAILY INGESTION OF FLUORINE AND ALUMINUM SULFATE BY CATTLE

Lot No.	1951		1952		1953		1951 through 1953	
	Mg. F per kg. body wt.[a]	Mg. $Al_2(SO_4)_3$ per kg. body wt.	Mg. F per kg. body wt.[a]	Mg. $Al_2(SO_4)_3$ per kg. body wt.	Mg. F per kg. body wt.[a]	Mg. $Al_2(SO_4)_3$ per kg. body wt.	Mg. F per kg. body wt.[a]	Mg. $Al_2(SO_4)_3$ per kg. body wt.
20A	.0999	-	.0708	-	.0345	-	.0863	-
20B	.1014	117.68	.0735	103.62	.0348	80.30	.0849	99.73
21A	.5386	-	.4554	-	.3727	-	.4935	-
21B	.5940	124.96	.5069	112.95	.3720	83.51	.5408	116.27
22A	.7812	-	.6426	-	.5918	-	.7212	-
22B[b]	.7885	115.50	.6911	103.20	.4929	76.32	.7190	107.03
23A	1.0032	-	.8793	-	.7332	-	.9332	-
23B	.9942	112.38	.8424	96.76	.6695	79.71	.9093	103.73
24A	1.2274	-	1.0173	-	.8144	-	1.0633	-
24B	1.2274	113.34	1.0338	96.84	.7066	67.43	1.1059	102.81

[a]Includes fluorine consumed in hay.

[b]Only 2 animals in this lot.

TABLE XVIII

AVERAGE DAILY FLUORINE BALANCE OF INDIVIDUAL ANIMALS FED VARIOUS LEVELS OF FLUORINE AND ALUMINUM SULFATE

Lot number	Animal number	Fluorine - Miligrams				Per cent F retained
		Intake	Urine	Feces	Balance	
20A	100	59.6	17.8	20.0	21.8	36.6
	102	53.6	37.8	34.8	-19.0	-
20B	103	61.7	18.2	28.7	14.8	24.0
	104	50.8	14.1	25.5	11.2	22.0
	106	223.4	88.8	37.4	97.2	43.5
21A	107	221.2	82.9	72.0	66.3	29.8
	108	204.0	66.2	55.5	82.3	40.3
21B	109	232.9	50.2	111.5	71.2	30.6
	111	414.0	39.4	127.2	47.4	22.1
22A	114	301.6	198.4	66.7	36.5	12.1
	117	326.4	37.1	145.9	143.4	43.9
22B	112	322.4	58.4	171.3	92.7	28.8
	116	324.2	67.1	161.0	96.1	29.6
	120	414.4	95.0	70.2	249.2	60.1
23A	118	420.1	149.0	78.2	192.9	45.9
	115	412.5	82.9	66.0	263.6	63.9
23B	123	254.2	62.7	154.0	37.5	14.8
	121	386.1	75.9	200.7	109.5	28.4
24A	124	449.8	184.6	101.5	163.7	36.4
	122	426.0	14.8	143.5	267.7	62.8
	129	506.9	67.4	218.7	220.8	43.6
24B	127	512.1	102.7	241.0	168.4	32.9
	128	504.8	92.5	182.5	229.8	45.5

TABLE XIX

CLASSIFICATION OF THE EFFECTS OF DIETARY FLUORINE ON TEETH OF CATTLE

Revised March 12, 1954
Confidential - Animal Husbandry-Veterinary Science Department
University of Tennessee

Classification	Wear greater than normal for age and conditions	Chalkiness or Mottling (Incisors)				Staining	Caries and/or erosions	Hypoplasia		Relative effects greater than normal on each tooth	Classification
		Focal	Cross Chalky	Chalky striations-Cross or longitudinal	Porcelain Excessive			Enamel	Tooth		
1a	Depends on age and individual variations		May be very slight Luster-good							None	1a
1b	Depends on age and individual variations		Slight to medium Luster-good		May be very slight	May be suspiciously discolored				None	1b
2	Depends on age and individual variations		Slight to diffuse Luster-good to fair		Slight to medium	Usually very slight to heavy brown				Questionable to slight	2
3	Table surface may be good on cattle to 6 years of age		Slight to heavy Luster-good to fair		Slight to heavy	Usually slight to heavy	Usually pathognomonic			Slight	3
4	Table surface may show negligible to medium wear		May show some of the above effects Lusterless		Slight to heavy May be only partially	Slight to excessive brown and black stain	May be precarious or carious after 1 or 2 years in wear	Suspected to slight	None	Slight to medium	4

"X" when added to classification number denotes an abnormality other than those traceable to fluorine

Boldface terms indicate symptoms which would definitely determine the classification of a tooth.

Corrected and accepted September 14, 1953 by Hobbs, Phillips, Greenwood, Moorman, Merriman and Griffith

TABLE XIX

CLASSIFICATION OF THE EFFECTS OF DIETARY FLUORINE ON TEETH OF CATTLE (continued)

Revised March 12, 1954
Confidential - Animal Husbandry-Veterinary Science Department
University of Tennessee

Classification	Wear greater than normal for age and conditions Focal	Cross chalky	Chalky striations-Cross or longitudinal	Porcelain	Excessive	Staining	Caries and/or erosions	Enamel	Tooth	Relative effects greater than normal on each tooth	Classification
5a	Wear variable Slight to medium	May show some of the above effects			May be partially	Slight to excessive brown and black stain	Progressive type of erosions may be present	Slight to medium	May be suspicious	Medium	5a
5b	Wear variable Slight to excessive				May be partially	Slight to excessive brown and black stain	Progressive type of erosions may be present	Medium to heavy	May be slight to medium	Medium to heavy	5b
5c	Medium to excessive wear				May be partially	Slight to excessive brown and black stain	Progressive type of erosions may be present	Heavy to excessive	May be medium to excessive	Heavy to excessive	5c

"X" when added to classification number denotes an abnormality other than those treaceable to fluorine.

Boldface terms indicate symptoms which would definitely determine the classification of a tooth.

Corrected and accepted September 14, 1953 by Hobbs, Phillips, Greenwood, Moorman, Merriman and Griffith.

TABLE XX

AVERAGE DAILY INGESTION OF FLUORINE AND ALUMINUM SULFATE BY SHEEP

Lot No.	1950		1951		1952		1950 through 1952	
	Mg. F per kg. body wt.[a]	Mg. $Al_2(SO_4)_3$ per kg. body wt.	Mg. F per kg. body wt.[a]	Mg. $Al_2(SO_4)_3$ per kg. body wt.	Mg. F per kg. body wt.[a]	Mg. $Al_2(SO_4)_3$ per kg. body wt.	Mg. F per kg. body wt.[a]	Mg. $Al_2(SO_4)_3$ per kg. body wt.
I	.1712	-	.4057	-	.1209	-	.2056	-
II	.8161	-	1.0618	-	.8335	-	.9091	-
III	1.4959	-	1.8815	-	1.5888	-	1.6521	-
IV	1.4878	64.13	1.8381	71.41	1.4611	65.60	1.6154	67.65
V	2.7417	-	3.2603	-	3.2699	-	3.0022	-
VI	2.5675	117.66	3.3768	141.88	2.7110	123.90	2.8889	129.53

[a]Based on amount added and amount in hay.

TABLE XXI

FLUORINE CONTENT OF BONES FROM SHEEP FED VARIOUS LEVELS OF FLUORINE AND ALUMINUM SULFATE[a]

Lot I	Lot II	Lot III	Lot IV	Lot V	Lot VI
		Metacarpals			
660	2600	5100	4200	5900	5200
1100	3500	4000	3600	6200	3800
1800	2700	4200	3600	5400	3600
430	3100	3800	3200	12100	4900
780	2500	5500	4900	5800	
850	2000	3600	4200	12100	
Av. 937	2733	4367	3950	9717	4375
		Mandibles			
1200	5400	8500	8300	12000	9500
1600	6400	8800	6500	12000	8200
1300	5400	9200	6800	11000	9500
1400	5400	8500	7500	17000	9900
1300	4900	9200	7600	12000	
1100	3900	8200	8700	8000	
Av.1317	5233	8733	7567	12000	9060
		Ribs			
900	6000	10700	6500	11700	12300
1600	7100	10500	5900	11800	8200
1700	5500	8600	7600	11200	9300
8300[b]	5400	9800	6200	16600	9100
1300	4400	7800		12400	
1000	4000				
Av.2467	5400	9480	6550	12740	9340

[a]Statistical data shown in Table XV.

[b]This analysis double checked.