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Effects of Fluorine on Productivity and Longevity in Beef Cows

University of Tennessee Agricultural Experiment Station

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Through the 28 years that this project has been active, many University and Industry personnel have made major contributions to its success. Dr. C. S. Hobbs (deceased), the former Head of the Animal Husbandry — Veterinary Science Department and Dr. W. H. MacIntire (deceased), the former Head of the Agricultural Chemistry Department, provided leadership for the field and laboratory research studies. Many members of their respective staff were involved in this project.

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FOREWORD

Investigations of the relationships of fluorine to agriculture were initiated by the Tennessee Agricultural Experiment Station as early as 1920. Fluoride insecticides were studied and entomological results were reported.

Later chemical studies, begun in 1929, dealt with the occurrence of fluoride in the atmosphere, in rain and surface water, in phosphatic fertilizers, rock phosphate, and slags.

Farmers in Maury and Blount Counties in Tennessee complained of unexplained injury to their crops and livestock and, in 1947, a study of the purported effect of industrial fluoride effluents in these two areas was begun. Considerable exploratory work was necessary for the development and adaptation of procedures both for sampling and analysis of soil vegetation, air, rain water, and animal products. Various feeding, metabolism, and grazing experiments with cattle and sheep and with laboratory animals were conducted and the results published in the various papers cited herein.

A survey was conducted in Maury County in 1947-52 and it was observed that cattle grazing on land that had been mined for phosphate exhibited severe dental fluorosis. To follow up this observation in Sumner County, Tennessee, dental fluorosis was confirmed in cattle on farms which had been mined several years earlier but no chemical plant operations were located in the area.

This publication is the final chapter in the extensive series of research projects concerning the relationships of fluorine to agriculture. The projects have ranged from very basic type studies to field surveys of the effects of industrial fluoride effluents upon plant and animal life in Tennessee. The financial support for these fluorine studies was provided substantially by grant-in aid contracts with the Monsanto Chemical Company; Aluminum Company of America; Stauffer Chemical Company — formerly Victor Chemical Works; and the Hooker Chemical Company plus limited state and federal funds. The cooperative collaborations and the financial support provided by these corporations have been of inestimable value in the completion of this research.

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SUMMARY

In order to study the lifetime effects of level of naturally-occurring soil fluorine and nutritional level upon physiological changes in and performance of beef cattle, the experiment reported by Merriman and Hobbs (1962) was revised in 1962 and continued through 1968. The effects measured were fluorine (F) uptake by bones of cows and calves, changes in teeth condition, reproductive performance of the cows, and weight changes (rate of growth) of cows and calves.

Seven groups of cattle were managed according to one of the following treatments:

1. Low fluorine soil-good nutrition (LFS-GN).
2. Low fluorine soil-low nutrition (LFS-LN).
3. High fluorine soil-good nutrition (HFS-GN).
4. High fluorine soil-low nutrition (HFS-LN).

Soil F levels. Pastures used in the earlier phase which contained soil with less than 800 parts per million (ppm) fluorine were combined into three larger pastures and represented low fluorine soil (LFS). The pastures containing soil with over 1500 ppm of fluorine were combined into four pastures and considered to represent high fluorine soil (HFS).

Nutritional levels. Within each soil F level, two levels of nutrition were maintained. The low nutritional level (LN) was maintained during the spring-summer pasture season by controlling pasture height (mowing) and/or by reducing the pasture area with temporary fences. Hay intake of the LN cows was restricted during winter. The good nutritional level (GN) was provided by an abundant allowance of high-quality pasture forage during the pasture growing season and an adequate allowance of hay during the winter.

Fluorine in soils. The soil F concentration in LFS pastures was less than 800 ppm. The HFS pastures had more than 1500 ppm F. F content of soil samples from HFS pastures was higher ($P < .05$) than that of samples from LFS pastures.

Esophageal-fistulated steer forage samples. Esophageal-fistulated steers were used to collect samples representative of the chemical and botanical composition of the diets selected by grazing cattle. These "fistual forage" samples were adjusted for leaching due to saliva and fistula effects (selected forage samples) and compared to samples of available forage which were hand-clipped about every 50 paces in a predetermined pattern. The mean F content of the available and fistual forage samples were similar. In contrast, adjustment of the fistual forage samples for salivary leaching resulted in a slightly higher F content in selected (fistula) forage samples than in available

forage samples. These results indicated that the traditional method of characterizing F content of ingested forage by randomly clipping forage throughout the pasture was relatively accurate. They further indicate that if any error existed, hand-clipped forage samples may have slightly under-estimated the F content of forage ingested by grazing animals.

Mature weight of cows. Quarterly body weights were used to calculate weight-age curves for individual cows. Estimates of mature weight (a), a general rate of maturing (k), and a parameter (b) which is closely associated with birth weight and early weight changes replaced the array of individual weights in evaluating factors affecting weight-age relationships. Cows provided adequate nutrition were 76 pounds heavier at maturity than those subjected to the lower level of nutrition. Cows grazing pastures grown on LFS were 66 pounds heavier at maturity than those grazing HFS pastures. Growth curve parameters indicated that the effects of LN and HFS on mature weight were additive. Cows in the HFS-LN group weighed 988 pounds at maturity compared to 1,131 pounds for the LFS-GN cows. The HFS-GN and LFS-LN cows were similar in mature weight and intermediate between LFS-GN cows and LFS-LN cows.

Fluorine concentration in bones. Samples from the right metacarpal (RMC) of each individual animal in experiment (1962 through 1968) were used to evaluate the effect of soil F level, nutritional level, and age of the animal on bone F content. These three factors accounted for about 99% of the variation in RMC fluorine content. The mean F content of the RMC of cows in the HFS groups in 1969 was 70% greater ($P < .001$) than that of the LFS cows (3253 vs 5540 ppm). The F content of bone samples from LN cows was slightly higher than that of GN cows; however, this difference was not statistically significant ($P > .05$). Bone F content increased as age increased and the rate of F accumulation was higher in HFS cows than in LFS cows. Accumulation of F in bone appeared to be primarily dependent on the concentration of F in the ingested feed and the period of time over which such ingestion occurred.

Fluorine concentration in calf bones. The RMC of LFS and HFS calves at birth had 220 and 386 ppm, respectively. This difference in bone F content between newborn calves of the two groups suggests that the rate of accumulation of F in the bones of the unborn calf is influenced by the F content of forage. Fluorine accumulation was more rapid in young calves than in older animals.

Fluorine in pasture forage and hay. Forage samples from both the HFS and LFS pastures were significantly higher in F ($P < .01$) in winter than in summer. In summer, average F content of the HFS forage was 125 ppm compared to 37 ppm for LFS forage. Fluorine content of the forage was significantly ($P < .01$) correlated with pasture grades which were objective scores assigned at 2-week intervals when each pasture was visually evaluated. Coefficients of correlation between forage F content and minimum, average, and maximum pasture height were -0.326, -0.323, and -0.298, respectively. During summer, the F content of forage samples from LN pastures was higher than that of forage samples from GN pastures for both HFS and LFS.

Teeth. Information on nomenclature and classification of incisor teeth is presented. Pictures of incisor teeth of selected cows at different age are shown to illustrate denture changes which occur due to ingestion, before eruption of affected teeth, for an extended period of time of forage grown on HFS and LFS. Average classification of incisor teeth tended to increase (a higher classification represented more pronounced fluoritic lesions) as age of cow increased from 2 to 4 years of age due to eruption of teeth bearing more marked fluoride lesions. This increase was greater ($P < .01$) in cattle grazing HFS pastures than in those grazing LFS pastures. After 4 years of age the average classification tended to decrease in all groups; however, the rate of decline was greater for the HFS cows. This significant decline in teeth classification of the HFS cattle was probably due to the wearing away of certain fluoride-induced lesions.

General health. Neither the F level in soil and forage nor the level of nutrition had any effect upon the general health of the animals.

The occurrence and degree of fluorosis in cattle, as well as teeth effects, in this experiment depended on the following factors: 1) the level of fluorine ingested, 2) age of the animal and stage of development, and 3) length of time exposed to increased fluorine ingestion.

Results from this study indicate also that F content of forage was influenced by soil F level, season of the year, and grazing intensity. These facts should be considered when F tolerance levels are established in an area of high F soils.

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by J. B. McLaren and G. M. Merriman*

INTRODUCTION

Among the elements in the earth's crust, fluorine (F) is twentieth in abundance. Due to its extreme reactivity, F occurs naturally only in combination with other elements in such forms as cryolite, apatite, and rock phosphate. Following the introduction in the 1920's of phosphorus supplements for livestock in the form of raw rock phosphate and phosphatic limestone, it was observed that they caused abnormal tooth abrasions, affected bones, and also altered the general health as reflected by depression in appetite (Reed and Huffman 1930). This problem was defined by Taylor (1929) and Reed and Huffman (1930) as fluorosis resulting from ingestion of (fluorides) in the mineral supplements.

Fluorosis of cattle and sheep is a chronic, insidious, and cumulative intoxication which interferes with cellular respiration by attacking the enzyme system according to Larner (1950), Phillips et al. (1934), Murray and Wilson (1946), and Summer et al. (1947). Blakemore et al. (1948) further suggested that early stages of fluorosis are characterized by stunted growth, intermittent lameness, mottling and irregular tooth wear, rough hair coat, low milk production, and poor condition. These early symptoms are followed by permanent lameness, emaciation, and difficulty in rising due to osteoporosis. As the disease progresses, periosteal bone thickenings may appear on the mandibles, ribs, lower limbs, and the digits (finger or toe); and, with advanced osteoporosis, the ribs become brittle. The bone fluorine content may exceed 5000 parts per million (ppm), compared to a normal of 500 to 1000 ppm according to Blakemore et al. (1948).

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Roholm (1937) states that dental changes are the most easily recognized and the most easily reproduced of all symptoms of chronic F poisoning. The earliest and mildest change is slightly-mottled enamel of permanent incisors in animals ingesting F during tooth formation and eruption. This mottling is expressed as chalky-white spots of hypoplasia which become brown or black and are pitted as damage increases. The general discoloration of the teeth varies from the usual yellow to brown or black. In more advanced stages, the incisors are shortened from abnormal wear due to softness of the enamel and the table surface of the tooth is rounded. Interior surfaces of cattle incisors are roughened due to longitudinal ridges in contrast to normal, smooth, and glossy-white teeth.

Fluorosis in livestock may develop through several channels. One source of contamination is the use of mineral supplements containing excess F. Such minerals include rock phosphate (3 to 4% F) and phosphatic limestone which contains F in proportion to the amount of phosphorus present.

Chronic fluorosis in farm animals, both in this country and abroad, has been reported in areas adjacent to industrial plants emitting gases and dusts containing fluorine. Livestock ingest F by grazing forages or consuming hays on which these gases and dusts have settled. Emissions of F occur in the production of superphosphate and defluorinated phosphate, in the smelting production of aluminum, in the manufacture of bricks from fluorine-bearing clays, in calcining of ironstone, and in certain enameling processes when emissions are not controlled. MacIntire **et al.** (1958) cited figures for one manufacturer of phosphate fertilizers indicating average daily emissions of 3,000 to 4,000 pounds of fluorine. Also industrial operations that use bauxite, cryolite, feldspar, or sodium fluoride as a flux may contaminate the atmosphere with fluorine (Murray and Wilson, 1946).

Another major source of F contamination of forage is from soils containing high concentrations of F. Soil can be deposited upon the forage by rain splash or wind-blown dust (MacIntire **et al.**, 1949; MacIntire **et al.**, 1958; Neeley and Harbaugh, 1954; Merriman **et al.**, 1956). Basically, fluorine in these soils has properties similar to those of F in raw-rock-phosphate.

As early as 1947, personnel of the Tennessee Agricultural Experiment Station were aware that a problem of fluorosis existed in parts of Middle and East Tennessee. A large area of Middle Tennessee is composed of a "phosphate basin" in which soil and rock are high in phosphates and consequently high in fluorine.

The 8-year experiment reported in this bulletin concludes about 22 years of research on fluorosis in beef cattle and sheep conducted by the Department of Animal Science at the University of Tennessee.

SCOPE AND OBJECTIVES

In order to determine the lifetime effect of naturally-occurring soil F upon physiological changes in and performance of beef cattle, the experiment reported by Merriman and Hobbs (1962) was continued with some revisions. Beef cows, heifers, and calves were grazed on pastures grown on soils near Franklin, Tennessee which varied in F content from 472 (low) to 3202 ppm (high). These treatments were combined with two levels of nutrition, restricted and normal energy levels, to study the interaction of level of fluorine ingestion and energy level. The area was apparently free of sources of F contamination.

This experiment was designed to provide additional information on the following:

1. Effects of soil-borne F on lifetime productivity of beef cows.
2. Degree of dental and/or systemic fluorosis in cattle grazing pasture grown on soil containing two general levels of F.
3. Influence of the nutritional level of cattle consuming forages containing F on the development of fluorosis.
4. Effect of soil fluorine content on the fluorine content of pasture and hay.
5. Afford a comparison of F levels in forage grazed and sampled by esophageal-fistulated steers and that of samples collected by the traditional hand-clipped method.

EXPERIMENTAL PROCEDURE

General. Hereford cows used in a previous study (Merriman and Hobbs, 1962) to determine the effects of naturally-occurring soil F on their general health and productivity were assigned to four treatments. Cows from the 18 original groups, shown in Table 1, were assigned to larger groups on the basis of previous soil fluorine and nutritional level.

Within each soil F level, two levels of nutrition were maintained. Due to weather variation among years and among various times within a growing season, the low nutritional level was maintained, especially during the spring-summer growing season, by controlling pasture height. The desired pasture height was maintained by mowing and/or reducing the pasture area by temporary fences.

Cattle. Seventy-six Hereford cows born during the period 1956 to 1959 and raised on the experimental pasture (Merriman and Hobbs, 1962) were used to initiate the experiment. Table 1 shows a

Table 1. Design of the experiment

Pasture number	No. of cows 4-1-61	Treatment[1] No.	Treatment[1] Description	Lots from[2] phase 1 combined	Included[3] cows from old lots
1	14	1	LFS-GN	11 & 13	1, 3, 11, & 13
2	5	2	LFS-LN	4	2
5	11	2	LFS-LN	12 & 14	4, 12 & 14
3	9	3	HFS-GN	5 & 7	5 & 7
7	10	3	HFS-GN	17 & 18	17 & 18[5]
4	10	4	HFS-LN	6 & 8	6 & 8
6	14	4	HFS-LN	15, 16, & 19	16 & 19[4]

[1]LFS — Low-fluorine soil.
HFS — High-fluorine soil.
GN — Good nutrition, adequate.
LN — Low nutritional level, short pasture.

[2]The pastures indicated from phase 1 (Merriman and Hobbs, 1962) were combined and grazed by the respective groups.

[3]All cows which were born and reared on the indicated pastures during phase 1 made up the respective groups.

[4]An area of pasture along German Creek was added to old pastures 16 and 19 to provide water and sufficient grazing for group 6.

[5]Cows in Pastures 6 and 7 were designated in 1961 to receive average to low nutrition during the last phase. However, cows in the old lot 17 had previously received GN and at the end of the first phase, cows in old lot 18 were heavier than other LN groups. In view of these facts and the abundance of forage availability in Pasture 7 from 1961 to 1969, this group was classified as GN. Based on the previous nutritional level, LN, of old lots 16 and 19 and forage available in Pasture 6, this group was classified as LN in this study.

list of the present treatments and the allocation of animals and pastures from the previous experiment to the respective groups in the current experiment.

No silage or concentrate was fed at any time during the experiment. Hay was fed during the winter (November 1 through March 30) when pasture forage was not sufficient to maintain gestating animals. The two nutrition (energy) levels were defined as follows: 1) rations of the cow groups designated to be fed at a "good" nutritional level were designed to provide about 80-100% of The National Research Council (NRC, 1960) recommended allowance during gestation and an abundant allowance of high-quality forage during the pasture growing season; 2) "low" nutrition rations provided about 60 to 70% NRC recommended allowance during gestation and limited or short pasture forage during the spring-summer pasture season.

All "good" nutrition (GN) cattle were fed supplemental hay in the summer when the pastures failed to supply adequate forage. Hay was not usually fed to the "low" nutrition (LN) groups, except in winter. Rate of winter hay feeding was about 1 to 1.5 pounds per 100 pounds of body weight for the LN groups and 2 pounds per 100 pounds of body weight for GN groups. Most of the hay fed to the various groups was raised on the pastures grazed by the respective group. The remainder was bought locally. Salt and dicalcium phosphate were the only mineral supplements fed to any group. All cows were weighed in November, January, June, and August each year. Cows were pasture-bred from early April to early or mid-July and heifers from May to August.

Calves were born on pasture and nursed their dams without creep until weaned in October or early November. Each calf was weighed, tattooed, and ear-tagged as soon as possible after birth. All calves were immunized against blackleg and malignant edema. At weaning, each calf was weighed, graded, and replacement heifers were selected to remain in the herd. Those selected for replacements were fed a ration of corn silage and a limited amount of concentrate during the winter. The remaining calves were removed from the experiment. The following April, each yearling replacement was assigned to the group in which she was born.

Pastures. Each cow-calf pair was provided with about 2 acres of pasture. The dominant pasture species were orchardgrass and ladino clover during the earlier years. Hop clover, lespedeza, bluegrass, and crabgrass were more prominent in later years. Fertilizer (P, K, and Ca) was applied annually according to soil analysis and agronomic recommendations. Individual pastures were overseeded when needed. Lespedeza, white clover, and orchardgrass was reseeded in combination or singly, depending on conditions.

Maintenance of pastures which provided the respective nutritional levels (LN, GN) designated for various groups was difficult, especially providing LN pastures without excessive abuse of the stand. To control the pasture height for each treatment, these steps were followed:

1. LN pastures were frequently clipped to a maximum height of 3 inches during the lush growing season.
2. GN pastures were clipped primarily for weed control.
3. When the height of LN pastures could not be controlled by clipping, an electric fence was used to restrict the grazing area available to the cows and hay was harvested from the ungrazed area.
4. When excessive forage was available in the GN pasture, the field was partitioned by an electric fence and the ungrazed area cut for hay to a stubble of 5 inches. Later, as

the cattle significantly shortened the grass in the restricted area, they were given access to the entire pasture.

The pastures were scored at approximately 2-week intervals during the grazing season to determine changes needed in pasture and cattle management and to describe the kind and amount of forage available. Values recorded when the pastures were scored were estimates of: percent of each species; maximum, minimum, and average height; stage of growth; and an overall grade or quality score.

EXAMINATION AND CLASSIFICATION OF CATTLE TEETH

Examination: Annual teeth classifications, measurements, and pictures were made on each animal 2 years old or over except in 1965. Cattle were restrained in a headgate and squeeze chute (Figure 1) with the nose elevated by a nose lead for the examination. Descriptions, classifications, and measurements of teeth were recorded on a dictation machine. Premolar and molar teeth were examined first. The presence of temporary teeth was noted. Any abnormal wear or stain was recorded for the permanent posterior teeth. Incisor teeth were wiped free of dirt and excessive moisture and examined without artificial light. The following observations on each permanent incisor tooth were recorded: chips on the cap, degree of luster, chalkiness or mottling, extra-enamel stain, intra-enamel stain, focal hypoplasia or caries and erosions, generalized enamel hypoplasia, tooth hypoplasis, relative degree of abnormal wear, and the overall classification. Classification of the incisor teeth was according to the scheme developed by Hobbs **et al.** (1954) and reproduced in this bulletin as Table 2. Photographs were made after the incisors were classified.

An Exacta V or VX camera, mounted on an aluminum frame (Figure 2), was used to make 35 mm color slides of the incisor teeth in the live animal (Hobbs, **et al.**, 1954 and Merriman and Hobbs, 1962). A label giving the cow number and date photographed was displayed on the photographic frame for future picture identification. During photographing, the camera frame mouthpiece was pressed against the depressed lower lip of the cow.

Interpretation of examinations. Abnormal staining and abnormal wear were described for permanent posterior teeth. A numerical rating was given each classification of an incisor tooth in calculation of an index as previously reported by Merriman **et al.** (1956). The classification of 1A was numerically equivalent to 0, 1B to 1, 2 to 2, 3 to 3, 4 to 4, 5A to 5, 5B to 6, and 5C to 7. The higher the numerical index of condition above 2, the more pronounced were the fluorotic lesions.

Figure 1. Cattle restraining equipment and camera used in the experiment.

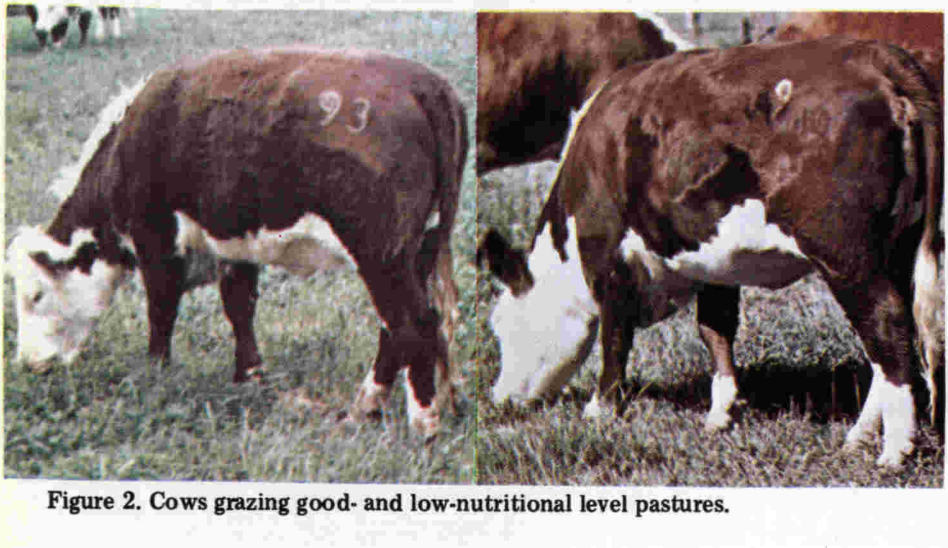

Figure 2. Cows grazing good- and low-nutritional level pastures.

Table 2. Classification of the effects of dietary fluorine on teeth of cattle

Classification	Wear greater than normal for age and conditions	Chaulkiness or mottling (Incisors)					Staining	Caries and/or erosions	Hypoplasia		Relative greater than normal on each tooth
		Focal	Cross Chalky	Chalky striations cross or longitudinal	Porcelain	Excessive			Enamel	Tooth	
1A	Depends on age and individual variations		[2]**May be very slight Luster—good**								None
1B	Depends on age and individual variations		**Slight to medium Luster—good**		May be very slight		**May be suspiciously discolored**				None
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
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 Pathognomonie			Slight
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 to 2 years in wear	**Suspected to slight**	None	Slight to medium
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
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
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

[1]This table is a reprint from University of Tennessee Agricultural Experiment Station Bulletin 235. Detailed definitions and explanations of nomenclature are given in Bulletin 235.

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

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

Sampling and Analytic Procedures

Soil Samples. F content of soil samples collected in March and July, 1955 (Merriman and Hobbs, 1962) was used as the basis of determining pasture boundaries in this experiment. Subsequent samples were taken in May 1962, March 1964, October 1964, July 1965, October 1965, and August 1968 and analyzed for F.

Collection and Preparation of Forage Samples. A sample of the forage from each pasture was hand-clipped once monthly during the time of sufficient forage for grazing. Forage was clipped at about every 50 paces in a pre-determined pattern. These clipped samples were intended to represent the average botanical and chemical composition of forage available in the pasture. Esophageal-fistulated animals were shown by Lesperance **et al.** (1960), Barth and Kazzal (1971), and Coleman **et al.** (1971) to provide a better means of measuring the chemical composition and digestibility of forage selected by grazing animals than did the traditional method of using randomly-clipped samples. In order to determine the reliability of the clipped samples used in this and previous experiments to estimate the amount of fluorine ingested by the animals, esophageal-fistulated steers were used to collect forage samples from pastures 1, 2, 3, 4, and 6 on the same dates that the clipped samples were collected. Methods of fitting the steers with esophageal fistulae, sampling, and adjustment procedures used in this study were described in detail by Mascola, Barth, and McLaren (1974).

Forage samples, both clipped and fistula, were placed in containers immediately after collection and 6 grams of calcium oxide was added to prevent the loss of F from the sample. The sample was dried at 60° C and ground in a Wiley Mill to pass through a 40-mesh screen. The method of Willard and Winter (1933)—described in detail by Merriman and Hobbs (1962) and Mascola, Barth, and McLaren (1974) employing perchloric acid distillation and thorium nitrate titration—was used to determine fluorine content. Fluorine content of forages was expressed on an "air-dry" basis.

Bone samples. Bone samples were not taken on a regular basis but samples of the mandible, right metacarpal, right metatarsal, tail, and 9th and 10th ribs were taken when an animal (cow or calf) died or was removed from the experiment and slaughtered.

Hair samples. Hair samples, for fluorine analysis, were taken from the hip and jaw regions of each animal just before terminating the experiment in April 1969.

Water samples. Monthly samples from the water available to each group was composited by 3-month periods and analyzed for F.

Statistical Analysis

The algebraic model proposed by Brody (1945) was used by Brown, Brown, and Butts (1972) to study weight-age curves in cattle and to evaluate the influence of various factors on growth. This procedure, described in detail by Brown, Brown, and Butts (1972b) simplifies the management of data. Many weights may be used in fitting the curve and, after estimates of three parameters (a, b, and k) are obtained, actual weights can be replaced by predicted weights—thus condensing the numerous measures on one animal to three values without loss of much information. The model provides estimates of weight (Y) at age t, mature weight (a), a general maturing rate (K), and a parameter (b) which is associated with the y-intercept and early weight changes.

Least-squares procedures (Harvey, 1960) were used to evaluate the effect of soil F level and nutritional level on the three parameters (a, b, and k) which measured growth characteristics.

Regression procedures were used to study the rate and magnitude of F accumulation indicated by bone analyses. Relationships among F content of various bones, urine, and hair were studied.

RESULTS AND DISCUSSION

Samples Collected By Esophageal-Fistulated Steers

Four esophageal-fistulated yearling Hereford steers were used over a 3-year period to collect forage samples representative of the chemical and botanical composition of the diets selected by grazing cattle on the same dates that samples of available forage were obtained. These samples will be referred to as "fistula forage" samples. Sampling of pastures 2 and 4 began during 1966 and continued through 1968 and pastures 1, 3, and 6 were sampled during 1967 and 1968. Since pastures 4 and 6 represented the same nutritional and fluorine level, they were combined and the samples were classified into four treatment groups as shown in Table 3. Fistula forage samples were adjusted for the leaching action of the saliva passing through the sample to yield a new variable which will be referred to as "selected forage."

The mean F contents of the fistula and selected forage samples and that of the corresponding samples of available forage are presented in Table 3. The mean F content of forage grown on low F soils was considerably lower than that of forage grown on high F soil. In addition, the F content of short forage in pastures providing a low level of nutrition was higher than that of the taller forage in pastures providing good nutrition.

Within pastures, the F content of available and fistula forage

Table 3. Raw means and standard errors for flourine content of "available forage," "fistula forage," and "selected forage" (air dry basis)

Pasture No.	Soil F	Nutritional level	Number of observations	Mean fluorine content: Available forage	Fistula forage	Selected[1] forage
				Parts per million		
1	Low	Good	35(10)[2]	25±3.4[3]	27±3.4	35[4]
2	Low	Low	71(29)	52±3.3	59±5.5	67[4]
3	High	Good	45(14)	91±17.8	99±14.6	107
4	High	Low	99(36)	138±14.3	137±13.7	145

[1]Adjusted for the leaching action of saliva passing through the samples.

[2]Several fistula and selected samples were paired with the comparable sample of available forage. The number of samples of available forage appears in parenthesis.

[3]Mean ± SE of the mean.

[4]Significantly different (P <.05) from available forage.

samples were similar. In contrast, adjustment of the fistula forage samples for salivary leaching resulted in a higher F content in selected forage samples than in available forage samples. The differences in F content of available and selected forage from high F soils were of similar magnitude as those from low-F soils. The standard errors reported in Table 3 indicated that the F content of both the availa- and fistula forage was extremely variable.

FACTORS AFFECTING F CONTENT OF FORAGE

In addition to soil-F level and plant height (nutritional level), the effects of several other factors (season, years, and individual animals) on the F content of forage selected by grazing cattle were studied in a multiple regression analysis. The variation in F content of selected forage among years was significant ($P<.01$), indicating that weather conditions or some undetermined factor caused the F content of forage to differ among years. The F content of selected forage was different ($P<.05$) among steers. Healy (1968) reported widely different soil intake by cows grazing the same pasture. They found that some cows consumed as much as 1,000 pounds of soil annually. Individual selectivity in grazing or difference in soil consumption probably accounted for the difference in F content among animals in this study. In addition, these factors may have caused variations in tooth changes and in the bone F content of animals grazing the same pastures.

Least-squares means of the F content of forage, presented in Table 4, indicated that the steers injected forage with higher average F content in the winter and spring than they did in the summer and autumn. In winter, the increase in F content probably resulted from additional accumulation of soil on the surface area of the plant during times when the plants grew slowly or were dormant.

Soil F level was found to affect the F content of forage ingested by grazing animals. F content of the selected forage increased about 3 ppm for each 100 ppm increase in soil F content. However, this relationship appeared to be curvilinear as shown in Figure 3. F content of the forage selected by the esophageal steers increased as soil-F content increased up to about 2000 ppm and no further increase in forage F content was observed.

These results show that the traditional method of characterizing ingested forage by randomly clipping forage throughout the pasture was relatively accurate. Mean F content of fistula forage samples and selected forage samples, shown in Table 3, tended to be higher than mean F content of available forage samples collected by the traditional method. However, the F content of the samples collected by esophageal-fistulated steers were not significantly ($P<.05$) different

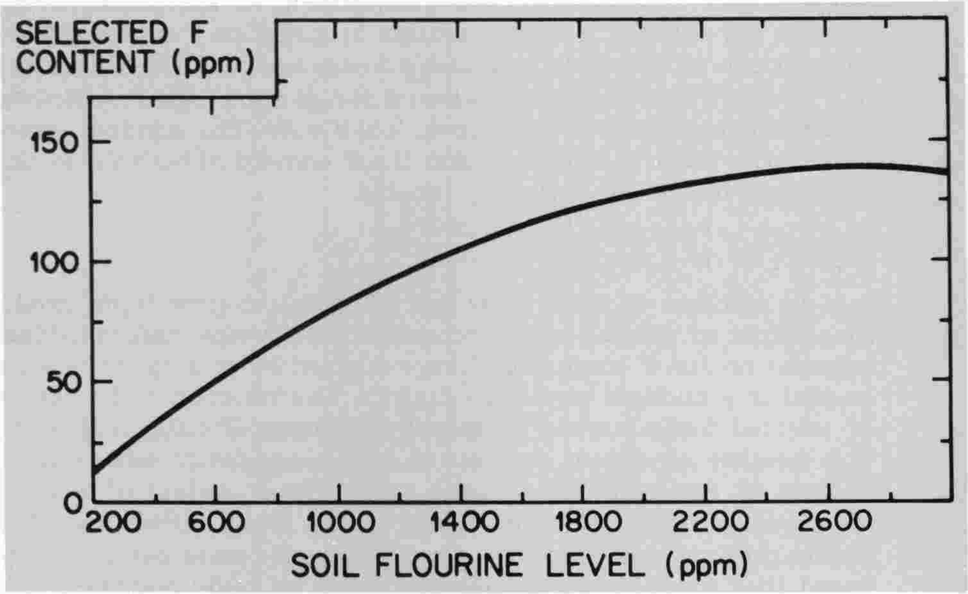

Figure 3. Relationship of F content of forage ingested by grazing steers with F content of the soil on which the forage was grown.

Table 4. Least-squares means and standard errors of F content of selected forage (ppm)

Variable	No. of observations	Mean	Standard error
Season[1]			
Winter	42	187	3.3
Spring	81	127	1.3
Summer	72	78	1.5
Fall	55	81	1.7
Year			
1966	34	149	2.7
1967	143	93	0.7
1968	73	113	1.3
Steer			
1	67	144	1.4
2	73	108	1.2
3	36	118	2.6
4	74	103	1.3

[1]Winter = January, February, and March; Spring = April, May, and June; Summer = July, August, and September; Fall = October, November, and December.

from the clipped (available) samples except for forage grown on low fluorine soils. These results indicate that if any error existed, hand-clipped or available forage samples may have contained slightly less F than forage ingested by grazing animals.

Sources of Fluorine In The Experimental Pastures

SOIL F LEVEL

Statistical analysis of the F content of soil samples indicated that there was no difference (P>.05) between samples collected at various times within groups (Table 5) except in pasture 7. Within sampling periods, F content of soil samples from HFS pastures (3, 4, 6, and 7) was generally greater (P <.05) than that of samples from the LFS pastures (1, 2, and 5). Soil F content of pastures 1, 2, 3, 4, and 5 were in general agreement with analysis reported by Merriman and Hobbs (1962). The lower soil F level reported in this study for pastures 6 and 7 is due, in part, to including additional areas next to the source of water supply in these pastures during this phase and not in previous years and also to the unexplainably low analysis for pasture 7 in March, 1964. These soil samples substantiate the grouping of the pastures in two categories, low (<800 ppm) and high (>1500 ppm) fluorine content.

Table 5. Soil fluorine content

	PASTURES						
	1	2	3	4	5	6	7
Sample-date	LFS+GN	LFS+LN	HFS+LN	HFS+GN	LFS+LN	HFS+LN	HFS+GN
	Parts per million						
May '62	450[e]	450[e]	2260[c]	3760[a]	650[e]	2800[b]	1450[d]
Mar. '64	748[d]	675[d]	2115[b]	4125[a]	480[d]	1405[c]	800[d]
Oct. '64	320[d]	555[d]	1800[b]	2510[a]	340[d]	1050[c]	1058[c]
July '65	425[c]	785[c]	2640[a]	2660[a]	445[c]	1520[b]	2190[a]
Oct. '65	430[c]	425[c]	2330[a]	2680[a]	555[c]	1180[b]	1970[b]
Aug. '68	660[d]	620[d]	2160[b]	3475[a]	360[d]	1170[c]	1730[b]
Average	506	585	2218	3202	472	1521	1533
C. V. %	32.2	23.4	12.4	21.1	25.0	42.7	34.9

a, b, c, d, e Means in each row superscripted with the same letter are not significantly different (P <.05).

FLUORINE CONTENT OF WATER

F content of pond water available to the cattle in various pastures varied throughout the 8-year period (Table 6). However, the F content of pond water furnished the HFS groups and the LFS groups were similar (P > .05).

Fluorine content of routine pasture forage samples. No known source of atmospheric F contamination existed in the area during the experiment. Therefore the concentration of F in pasture forage was

Table 6. Fluorine content of pond water

	GROUPS				
	LFS		HFS		
Year	1 and 5	2	3 and 4	6	7
	Parts per million				
1962	1.40(2)[a]	0.20(2)	0.30(2)	0.30(2)	0.44(2)
1963	0.79(1)	0.30(1)	4.08(1)	0.52(1)	0.72(1)
1964	1.03(4)	0.45(4)	2.87(4)	0.44(4)	0.77(4)
1965	0.77(4)	0.54(4)	1.34(4)	0.50(4)	0.53(4)
1966	1.28(4)	0.59(4)	1.03(4)	0.36(4)	0.53(4)
1967	1.10(3)	0.71(3)	0.89(3)	0.34(3)	0.46(2)
1968	1.22(4)	0.53(4)	1.58(4)	0.33(4)	1.42(4)
1969	1.14(1)	0.40(1)	1.30(1)	0.35(1)	0.84(1)
AVG.[b]	1.10	0.51	1.56	0.39	0.74

[a]Number in parenthesis is the number of samples indicated in the mean.

[b]Weighted average.

assumed to have resulted from plant uptake or from concentrations of F in the soil that was splashed or blown upon the plants.

Mean F content of the routine monthly forage samples collected during the summer (April through October) periods from 1961 through 1968 are shown in Table 7. The mean winter F content for these years are shown in Table 8. These data indicate that the concentration of F in the soil affected concentrations of F in vegetation grown upon that soil. The average F content of forage grown on the four high-fluorine soils (HFS) during the eight spring-summer pasture seasons was 125 ppm, with a coefficient of variation (C. V.) of 105.4%. Forage grown on the three low-fluorine soils (LFS) averaged 37 ppm F with a C.V. of 96%. The difference in F content between forage grown on HFS and on LFS was highly significant (P < .001). Average F content of the HFS vegetation during the seven winter seasons was 320 ppm (C.V. 55.9%) and that of the LFS forage was 103 ppm (C.V. 70.0%). The difference between the F content of HFS and LFS forage during winter was also highly significant.

Table 7. Fluorine content of pasture forage in summer[a]

Group	Treatment	Soil F Content[b]		Fluorine content, ppm																	
				1961		1962		1963		1964		1965		1966		1967		1968		1961-68	
		ppm	C.V.	Avg.	C.V.[c]	Avg.	C.V.	Avg.	C.V.	Avg.	C.V.	Avg.	C.V.	Avg.	C.V.	Avg.	C.V.	Avg.	C.V.	Avg.	C.V.
				Parts per million																	
1	LFS+GN	506	32	19[d]	44	22	51	17[d]	37	24[d]	34	31[d]	61	37[d]	56	21[d]	56	33[d]	103	26	69
2	LFS+LN	585	23	22[d]	116	32	74	20[d]	44	62[d]	106	52[e]	108	43[d]	40	54[e]	85	36[d]	52	41	95
5	LFS+LN	472	25	27[d]	30	31	34	20[d]	32	57[d]	93	53[e]	85	89[d]	86	41[e]	52	37[d]	64	45	94
Avg	LFS	521	27	23	45	28	55	19	37	48	104	45	93	56	89	38	83	35	76	37	96
3	HFS+GN	3202	21	67[de]	87	175[d]	81	75[de]	39	178[e]	46	268[f]	80	150[e]	102	225[f]	127	97[e]	92	155	104
4	HFS+LN	2218	12	71[de]	134	332[d]	22	125[e]	64	113[de]	61	241[f]	85	190[e]	45	214[f]	101	275[f]	72	189	83
6	HFS+LN	1521	43	93[e]	89	47	44	48[d]	48	78[de]	86	86[e]	72	84[d]	81	95[ef]	102	74[e]	76	78	83
7	HFS+GN	1533	35	50[de]	93	48	26	76[de]	73	69[de]	23	66[e]	135	78[d]	102	138[fg]	99	96[e]	92	80	98
Avg	HFS	2118	41	71	101	150	93	81	70	110	68	166	106	126	85	168	116	136	104	125	105

[a]Summer pasture samples include the routine monthly hand samples collected in April through October each year.

[b]Average soil F content based on samples collected between May 1962 and August 1968.

[c]Coefficient of variability (C.V.) is a ratio of the variation among samples within a group to the mean and permits comparison of variation among groups.

d, e, f, g Means within the same column superscripted with the different letters are significantly different ($P < .05$).

Table 8. Fluorine content of pasture forage in winter[a]

Group	Treatment	Soil F content[b] ppm	Soil F content[b] C.V.[c]	1962 Avg.	1962 C.V.	1963 Avg.	1963 C.V.	1964 Avg.	1964 C.V.	1965 Avg.	1965 C.V.	1966 Avg.	1966 C.V.	1967 Avg.	1967 C.V.	1968 Avg.	1968 C.V.	1962-68 Avg.	1962-68 C.V.
				Parts per million															
1	LFS+GN	506	32	56^{d}	58	95^{d}	54	153^{e}	91	77^{e}	58	78^{e}	47	86^{i}	48	71^{f}	56	90	76
2	LFS+LN	585	23	90de	46	150^{d}	82	120de	25	92^{e}	39	75^{e}	48	125^{id}	31	85^{f}	74	106	54
5	LFS+LN	472	25	119^{def}	89	107^{d}	46	82^{d}	27	79^{e}	11	123^{e}	45	179^{ed}	99	85^{f}	76	113	44
Avg.	LFS	521	27	88	76	117	67	118	70	83	38	92	50	130	82	80	62	103	70
3	HFS+GN	3202	21	224^{g}	109	448^{h}	49	434^{h}	18	292^{fgh}	58	232^{fg}	52	438^{g}	40	326^{gh}	31	354	46
4	HFS+LN	2218	12	362^{h}	23	267^{g}	70	392^{gh}	44	234^{f}	50	369^{h}	58	611^{h}	59	392^{h}	28	382	58
6	HFS+LN	1521	43	153de	83	215^{fg}	58	285^{f}	36	315^{d}	98	291^{g}	43	230^{e}	43	270^{g}	89	254	62
7	HFS+GN	1533	35	194^{efg}	53	258^{efg}	87	344^{fg}	36	311^{gh}	50	274^{g}	17	317^{f}	53	308^{gh}	3	288	49
Avg.	HFS	2118	41	235	60	303	65	364	35	288	63	291	52	399	62	324	40	320	56

[a]Winter pasture samples include the routine monthly hand samples collected in April through October each year.

[b]Average soil F content based on samples collected between May 1962 and August 1968.

[c]Coefficient of variability (C.V.) is a ratio of the variation among samples within a group to the mean and permits comparison of variation among groups.

d,e,f,g,h,i Means within the same column superscripted with the different letters are significantly different ($P < .05$).

Fluorine content of the forage was significantly ($P < .10$) negatively correlated with pasture grades which were objective scores assigned at 2-week intervals when each pasture was visually evaluated. Coefficients of correlation between F content of the forage sample and minimum, average, and maximum pasture height were -0.326, -0.323, and -0.298, respectively. These associations agree with other measures of this relationship since lush, rapidly-growing pastures were usually rated higher with respect to pasture grade.

Factors Affecting Variation in F Content Of Forage

F levels in vegetation were significantly higher ($P < .01$) in winter than in summer from both the HFS and LFS pastures. In general, F content of forage from the HFS and LFS pastures were more variable during the summer than in winter. The magnitude of the F content tended to be closely related to soil F content.

During the summer sampling seasons, F content of forage samples tended to align into three groups. Samples from pastures 1, 2, and 5 tended to be low in F content. Forage from pastures 3 and 4 tended to be high and that from pastures 6 and 7 tended to be intermediate in F. However, during winter sampling periods, this grouping was less evident and tended to align into two levels, high and low F content, with pastures 6 and 7 in the high group.

These seasonal differences may be due to the following possibilities:

1. In winter the grasses were dormant and the cattle grazed less. Thus, the vegetation was in a fixed place over a longer period of time and had more opportunity to be covered with blown or splashed soil particles than rapidly-growing and rapidly-consumed grass in the summer.
2. Winter stands and ground cover were generally sparse and available plants were short and close to the ground, thus contributing to increased contamination from splash.
3. Rainfall was heavier during the winter and resulted in greater contamination.

Level of nutrition: During the summer periods, there was a significantly greater concentration of F in the forage from low nutrition (LN) pastures than in the forage from the good nutrition (GN) pastures for both HFS and LFS. This appears to be due to grazing intensity. In order to maintain the lower nutritional level, it was necessary to graze the LN pastures closer than the GN pastures. In the more detailed study using esophageal-fistulated steers, F content of forage was inversely related to plant height ($r = -0.34$) at the time of sampling.

Years. F content of forage from the LFS groups (1, 2, and 5) was not significantly influenced by year differences when considered on a within-season basis. However, F content of forage grown on HFS varied from year to year during both summer and winter periods. Factors responsible for these year-to-year fluctuations included amount of precipitation and other weather conditions, rate of pasture growth, prevalence of dust conditions, and year-to-year variation in pasture density.

General considerations. When comparing F intake levels of this experiment with reported tolerance levels, one should consider the fact that during the winter months the experimental cattle received most of their ration in the form of hay. This practice was similar to average farm conditions in most areas. This resulted in a sharp decrease in F intake by the HFS groups during winter. None of the hay fed to the cows contained more than 32 ppm F (Table 9) and most hay contained less than 20 ppm F. F content of hay fed the various groups within a sampling period was similar ($P > .05$); however, F content of hays differed among sampling periods and among years.

The range in F content of vegetation produced in a given pasture in the same season may be the result of one or more of the following:

1. A single forage sub-sample for analysis could be greatly affected by small particles of soil that had a high F content.
2. Samples taken immediately after a rain that resulted in considerable soil splashed on the plants, or during a very dusty period, could be higher in F content than a sample taken from the same pasture during periods of fast plant growth.

Average monthly rainfall, by seasons, is presented in Table 10. Rainfall was generally greater in winter than in summer; however, these values do not reflect the potential effect of significant precipitation immediately before forage sampling on the F content of the sample. Accumulative precipitation for periods of 7 and 30 days before each sampling period was included in a statistical model to determine the effect of precipitation on variation in forage F content. A negative relationship between rainfall and forage F content was observed ($r = -0.012$ and $r = -0.028$, respectively). These relationships may represent the effect of the rainfall on forage growth rather than on soil splashed upon the plants, since the time included was 7 and 30 days before sampling. McIntire et al. (1958) suggested that forage samples collected immediately following heavy rainfall were higher in F than similar samples collected at other times.

Table 9. Average fluorine content of hays fed in winter

Year	GROUPS 1 LFS+GN	2 LFS+LN	3 HFS+GN	4 HFS+LN	5 LFS+LN	6 LFS+LN	7 HFS+GN
	Parts per million						
1962-63	13.3	15.3	15.7	31.0	13.3	10.7	15.0
1963-64	14.2	14.0	13.8	9.0	23.5	23.0	26.5
1964-65	12.8	11.8	10.2	8.4	12.0	14.6	16.6
1965-66	12.0	17.0	10.8	17.2	20.6	15.0	13.2
1966-67	15.0	28.2	15.8	16.0	14.2	11.2	9.0
1967-68	7.8	19.5	16.5	8.5	17.8	12.5	15.4
1968-69	24.2	25.5	20.5	31.8	16.2	23.2	22.5
MEAN	15.4	18.6	14.4	16.6	16.9	15.9	17.3
C.V. (%)	78.1	50.1	51.5	89.5	60.7	47.0	57.9

Table 10. Average monthly rainfall[a] by season

GROUP	Sum.[b] 1961	Win.[c] 1961	Sum. 1962	Win. 1962	Sum. 1963	Win. 1963	Sum. 1964	Win. 1964	Sum. 1965	Win. 1965	Sum. 1966	Win. 1966	Sum. 1967	Win. 1967	Sum. 1968	Win. 1968
	Inches of rainfall															
1	3.51	7.05	3.77	3.56	3.21	4.02	4.11	4.81	3.85	2.71	3.24	3.47	3.69	3.89	4.05	4.08
2	3.36	7.47	4.25	4.00	3.09	3.38	4.12	5.19	3.75	2.71	3.24	3.47	3.69	3.89	4.05	4.08
3	3.36	7.47	4.25	4.00	3.09	3.38	4.12	5.19	3.75	2.71	3.24	3.47	3.69	3.89	4.05	4.08
4	3.36	7.47	4.25	4.00	3.09	3.38	4.12	5.19	3.75	2.71	3.24	3.47	3.69	3.89	4.05	4.08
5	3.51	7.05	3.77	3.56	3.21	4.02	4.11	4.81	3.85	2.71	3.24	3.47	3.69	3.89	4.05	4.08
6	3.51	7.05	3.77	3.56	3.21	4.02	4.11	4.81	3.85	2.71	3.24	3.47	3.69	3.89	4.05	4.08
7	3.48	7.14	3.85	3.68	3.14	3.93	3.80	5.13	3.63	2.71	3.24	3.47	3.69	3.89	4.05	4.08

[a]Records were compiled from rain gauges on the experimental farms from the Summer of 1961 through the Summer of 1965, and from data compiled at the official weather station located at Franklin, Tennessee from the Winter of 1965, through the Winter of 1968.

[b]Summer — April through October (Sum.).

[c]Winter — November through March (Win.).

Animal Performance

Weights and gains of cows. Weights by periods and total gains for cows grazing the experimental pastures are shown in Table 11. Initially the cattle are grouped into two age classes, the older cows (born between 1956 and 1959) and the younger cows (born in 1960 and added to the experimental groups in 1961). However, beginning in November 1961, no distinction was made between old and young animals with respect to weight.

Average annual weight (average interval of 343 days) of the seven pasture groups (Table 11) indicates that changes in body weight of cows grazing the HFS and LFS pastures varied considerably from year to year. This could be due to normal fluctuation in temperature, rainfall, management practices, pasture quality, and other factors, which normally vary from year to year, since all of these factors are known to influence performance of cattle on pasture. Cattle grazing pastures grown on HFS tended to fluctuate less with respect to body weight than those grazing pastures grown on LFS.

Mean body weight and changes in body weight appeared to be similar for cows maintained at the low and high nutritional levels. This was in contrast to results of Merriman and Hobbs (1962) who reported that cows on GN pastures gained faster ($P<.01$) and were heavier than those on LN pastures. During the earlier phase of the experiment, reported by Merriman and Hobbs (1962), all of the cows were younger and more uniform in age than those in the current phase. Since this study was a continuation of the earlier phase reported by Merriman and Hobbs (1962) and since the major objective was to evaluate the long-term effects of soil F and nutritional level, annual mean body weight and body weight changes were considered inadequate to reflect these long-term effects. Since adequate weight records were available from which individual growth curves could be derived, it was more desirable to use these growth curves in reflecting the influence of F and nutrition level.

Factors affecting lifetime growth patterns of the cows. Estimates of mature weight (a), a general rate of maturing (k), and a parameter (b)—which is closely associated with birth weight and early weight changes—are presented in Table 12 for cows raised on the high and low fluorine soils at two nutritional levels (adequate and low). Growth curves which represent differences in growth patterns between the four combinations of soil fluorine and nutritional levels are illustrated in Figure 4. These curves were calculated using the Algebraic model applied by Brody (1945) to study weight-age relationships in cattle and to estimate parameters (a, b, and k) shown in Table 12.

Table 11. Weights and gains of cows[a]

Treatment[a]	Group No.	Average initial weight		Nov. 1961 Avg. wt. & gain		Sept. 1962 Avg. wt. & gain		Dec. 1963 Avg. wt. & gain		Sept. 1964 Avg. wt. & gain		Oct. 1965 Avg. wt. & gain		Oct. 1966 Avg. wt. & gain		Oct. 1967 Avg. wt. & gain		Oct. 1968 Avg. wt. & gain		1961 to 1968 Avg. wt.
										Pounds										
LFS+GN	1	967[b]	642[c]	1052	159(83)[d]	1004	-48(79)	1108	81(111)	1093	-15(83)	1205	94(86)	1210	-10(96)	1150	-60(140)	1054	-52(71)	1066
LFS+LN	2	1000	632	1120	270(113)	1047	-73(86)	1150	103(139)	1182	32(90)	1110	-72(124)	1200	45(28)	1120	-60(61)	1025	-22(31)	1090
LFS+LN	5	836	620	1010	222(59)	993	-38(75)	1131	196(66)	1062	-73(43)	1153	92(97)	1094	-58(58)	1148	54(82)	985	-135(47)	1026
Avg. LFS		918	633	1045	197	1005	-47	1123	127	1098	-27	1169	64	1163	-18	1143	-16	1022	-79	1055
HFS+GN	3	881	642	958	109(122)	897	-40(61)	993	98(119)	1055	-62(119)	1099	39(109)	1144	67(56)	1115	-35(26)	1014	-78(70)	995
HFS+LN	4	840	635	923	158(117)	995	32(117)	1018	63(110)	1020	-36(56)	894	-133(55)	1004	110(112)	1064	61(79)	938	38(74)	953
HFS+LN	6	876	622	976	164(85)	910	-68(71)	1037	130(75)	1005	-32(80)	1078	73(56)	1075	-2(81)	1084	16(63)	980	-94(67)	982
HFS+GN	7	953	775	1126	186(80)	976	-125(87)	1141	164(70)	1114	-45(98)	1185	59(117)	1208	22(115)	1188	-28(29)	999	-132(58)	1092
Avg. HFS		890	641	993	157	931	-55	1049	116	1044	-20	1063	14	1101	42	1110	10	981	-73	1004

[a]Days per period: 210, 325, 431, 289, 406, 355, 360, and 365 for 1961 to 1968, respectively. All values are weighed means.

[b]Cows born 1956-59, initial weight taken 3-28-61.

[c]Cows born 1960, initial weight taken 5-18-61.

[d]Number in parenthesis is the standard deviation and indicates the variation among cows within each group.

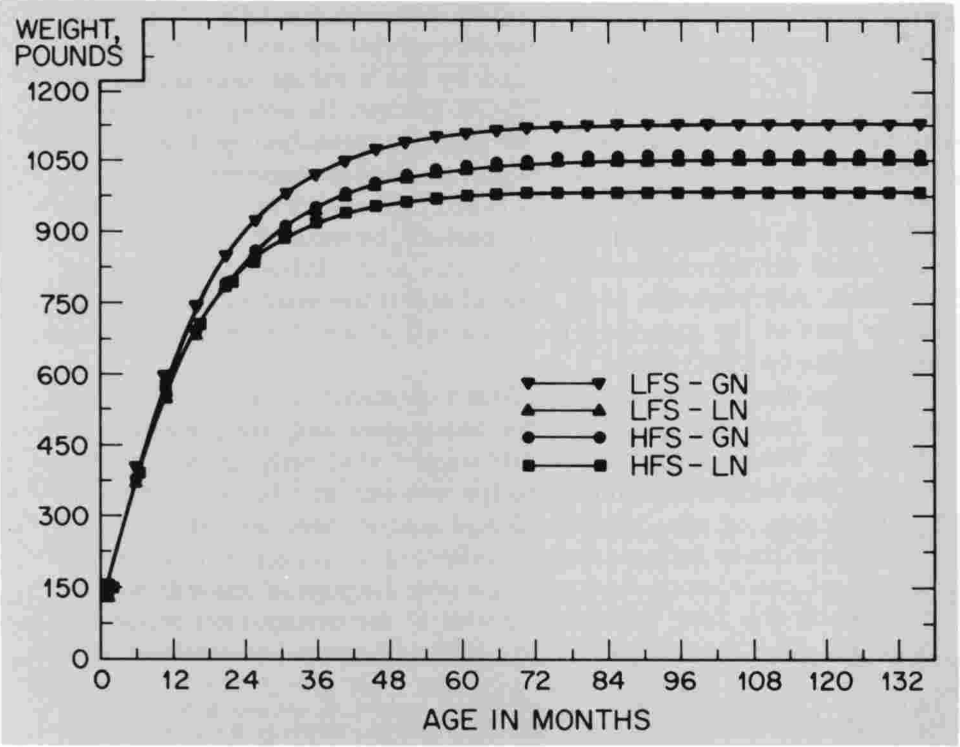

Figure 4. Mean growth curves of females raised on high and low fluorine soils with low and good levels of nutrition.

Table 12. Mean estimates of growth parameters

Parameter	LFS LN	LFS GN	HFS LN	HFS GN
a	1055 ± 26	1131 ± 29	988 ± 22	1066 ± 25
b	958 ± 24	1069 ± 27	922 ± 21	982 ± 24
k	.061 ± .004	.060 ± .004	.072 ± .003	.060 ± .003
No. of observations	20	17	30	20

Cows provided adequate nutrition were 76 pounds heavier at maturity than those subjected to a low level of nutrition. Cows grazing pastures grown on LFS were 66 pounds heavier at maturity than those grazing HFS pastures. Growth curves presented in Figure 4 indicate that the effect of LN and HFS on mature weights were additive. Cows in the HFS-LN group weighed 988 pounds at maturity compared to 1,131 pounds for the LFS-GN group. Cows in the other groups, HFS-GN and LFS-LN, were similar in mature weight and tended to be intermediate between the LFS-GN and the HFS-LN groups.

Rate of maturing, represented by the k values, was similar for the LFS-LN, LFS-GN, and HFS-GN groups. However, the rate at which the cows in the HFS-LN group approached maturity was faster than that in the other three groups. This is supported by results obtained by Merriman and Hobbs (1962) who reported no significant difference in calf gains due to soil, pasture, or water F levels and that only small differences were observed due to the influence of levels of nutrition. Although the cows grew at about the same rate during the earlier part of the growth period, the rate at which they approached mature size (weight) varied.

Mean weight of cows in the four treatments at various ages were estimated from the growth curve parameters and are presented in Table 13. These estimated weights suggest that early growth of the cows in the various treatment groups was similar. However, after 16 to 20 months of age, nutritional and soil F level tended to affect growth and these influences were reflected in the estimated mature weights of the various treatment groups. Percent of mature weight attained by the four treatment groups at various ages are shown in Table 14. At 8 months of age, the HFS-LN group had attained 48%

Table 13. Least-squares means of estimated weight at various ages for cows raised on high and low fluorine soils with high and low nutritional levels

	Treatment			
	LFS		HFS	
Age in months	LN	GN	LN	GN
	Estimated weight in pounds			
4	265	181	305	243
8	437	384	476	419
12	572	545	604	557
16	678	671	701	666
20	760	769	773	722
24	825	847	827	819
36	945	993	920	946
48	1002	1065	960	1007

of their mature size compared to 39.2, 41.4, and 34.0% for the HFS-GN, LFS-LN, and LFS-GN treatments, respectively. However, at 48 months of age all treatments had attained 94% or more of their mature weight. The effect of soil F content and nutritional level on estimates of mature weight and rate of maturing in this study are similar to the influences of these factors on cow weight and daily gain reported by Merriman and Hobbs (1962). These results indicate

Table 14. Least-squares means for degree of maturity at various ages for cows raised on high and low fluorine soils with high and low nutritional levels

Age in months	TREATMENT			
	LFS		HFS	
	LN	GN	LN	GN
	Percent maturity (U)			
4	25.1	16.0	30.9	22.8
8	41.4	34.0	48.2	39.2
12	54.2	48.1	61.1	52.2
16	64.2	59.3	70.9	62.5
20	72.0	68.0	78.2	70.5
24	78.1	74.9	83.6	76.8
36	89.6	87.8	93.1	88.7
48	95.0	94.1	97.1	94.5

that the influence of these factors is greater with respect to mature weight than their influence on gain during the early part of the growth period when early growth is measured as the change in body weight between two dates.

Reproductive performance. The number of cows in the respective groups during each breeding season (1962 through 1968) and the number of those cows that calved each year are shown in Table 15. The effects of soil F content and nutritional level on reproductive performance of all cows during this 7-year period are shown in Table 16. Of the 209 cows in the LFS groups during the seven breeding seasons, 183 of them calved (87.6%). This was similar to the 86.2% calving performance (257 of 298 cows exposed) in the HFS groups. These results were similar to those reported by Merriman and Hobbs (1962) except reproductive efficiency was about 10% lower for both groups than in the early phase. This decrease was probably due to greater variation in age among the cows during the last 7 years. Lower reproductive performance is generally associated with younger and older cows. Mortality rate among calves in the HFS and LFS groups was similar (Table 16) during the period 1962 through 1968.

Calving percentage for the GN cows (88.9%) was higher than that of the LN cows (83.2%). However, the mortality rate from birth to weaning was similar for the two treatment groups. Eighty-nine percent of the calves born in the GN groups were raised to weaning compared to 90% in the LN groups.

In all years dystocia (difficult calving) was a major problem. However, there was no relationship between the incidence of dystocia and soil F or nutritional level. The high incidence of calving difficulty was probably due to several factors:

Table 15. Reproductive performance of cows and daily gains of calves

Treat-ment	Group No.	1962 No. of cows	1962 No. cows calv-ing	1962 Calves raised No.	1962 Calves raised Adjusted da. gain	1963 No. of cows	1963 No. cows calv-ing	1963 Calves raised No.	1963 Calves raised Adjusted da. gain	1964 No. of cows	1964 No. cows calv-ing	1964 Calves raised No.	1964 Calves raised Adjusted da. gain	1965 No. of cows	1965 No. cows calv-ing	1965 Calves raised No.	1965 Calves raised Adjusted da. gain	No. of cows
LFS+GN	1	20	17[a]	15	1.58	20	14[b]	12	1.64	14	13	13	1.92	13	12	9	1.78	13
LFS+LN	2	5	5	5	1.62	5	4	4	1.80	5	4	9	2.03	5	4	4	1.84	4
LFS+LN	5	15	14	12	1.59	14	10	10	1.62	10	9	9	1.75	10	7	7	1.73	10
TOTALS		40	36	32	1.59	39	28	26	1.66	29	26	26	1.88	28	23	20	1.77	27
HFS+GN	3	9	9	9	1.40	10	7	6	1.50	8	6	5	1.72	8	4	4	1.38	7
HFS+LN	4	10	6[a]	6	1.73	10	6	5	1.63	10	10	9	1.59	10	10	10	1.48	10
HFS+LN	6	18	16	15	1.16	18	15	8	1.49	14	13	13	1.50	14	12	10[c]	1.53	14
HFS+GN	7	10	9	9	1.90	10	9	9	1.59	10	10	9	1.83	9	7	6	1.82	41
TOTALS		47	40	39	1.47	48	37	28	1.55	42	39	36	1.64	41	33	29	1.54	41

[a]One cow aborted, not included. [b]Three cows aborted, not included [c]One calf sick, not included.

Table 15. Reproductive performance of cows and daily gains of calves (continued)

Treat-ment	Group No.	1966			1967				1968				1962-68			
		No. cows calv-ing	Calves raised No.	Calves raised Adjusted da. gain	No. of cows	No. cows calv-ing	Calves raised No.	Calves raised Adjusted da. gain	No. of cows	No. cows calv-ing	Calves raised No.	Calves raised Adjusted da. gain	No. of cows	No. cows calv-ing	Calves raised No.	Calves raised Adjusted da. gain
LFS+GN	1	13	10	1.71	11	10	10	1.88	9	9	8	1.72	100	88	77	1.74
LFS+LN	2	3[a]	3	1.98	5	3	2	1.78	3	2	2	1.74	32	25	24	1.82
LFS+LN	5	10	10	1.60	10	7	7	1.86	8	8	7	1.70	77	65	62	1.68
TOTALS		26	23	1.70	26	20	19	1.86	20	19	17	1.71	209	178	163	1.75
HFS+GN	3	7	7	1.92	6	6	6	1.91	5	4	4	1.63	53	43	41	1.64
HFS+LN	4	9	9	1.64	10	5[a]	5	1.78	10	8	8	1.46	70	54	52	1.60
HFS+LN	6	11	11	1.58	14	14	13	1.58	14	12	7	1.58	106	93	77	1.47
HFS+GN	7	10	9	1.99	10	10	8	1.88	10	10	10	1.69	69	65	59	1.81
TOTALS		37	36	1.76	40	35	32	1.75	39	34	29	1.59	298	255	229	1.62

[a]One cow aborted, not included. [b]Three cows aborted, not included [c]One calf sick, not included.

Table 16. Reproductive performance of all cows from 1962 through 1968

	Cows calving[1]		Calves weaned vs. those born[2]	
	Percent			
Low Fluorine Soil (LFS)	87.6		89.1	
Good Nutrition (GN)		92.0		83.7
Low Nutrition (LN)		84.0		93.9
High Fluorine Soil (HFS)	86.2		89.9	
Good Nutrition (GN)		87.7		93.8
Low Nutrition (LN)		83.9		88.4
All Good Nutrition		88.9		89.0
All Low Nutrition		83.2		90.0

[1]Ratio of number of cows calving to those exposed.

[2]Ratio of number of calves weaned to number born.

1. Two-year-old heifers were used to maintain the designated stocking rate when older cows died or had to be removed from the experiment.
2. Yearling heifers, bred to calve as 2-year-olds and maintained on pastures with older cows, were at a distinct disadvantage.
3. The experimental design required maintaining cows on their respective pastures during calving. These pastures were located on three separate farms and it was impossible for the herdsman to observe the cows during the night. In addition, the arrangement of the herds also limited observations during the day and prevented detection of cows which were having calving difficulty as early as might have been possible if the cows could have been maintained in a single herd.

Lifetime effects on reproductive performance. The major objective of this study was to evaluate the effect of soil F and nutritional level on lifetime performance of cows. The cows in this phase of the study were born in 1956 through 1961 and had been exposed to the respective soil F and nutritional level for 8 to 13 years. In order to evaluate the cumulative effects of these factors, the reproductive performance of the cows exposed to the various treatments for an extended period was considered separately. Results of this analysis, presented in Table 17, show that 86.5% of these cows in the LFS groups calved annually compared to 85.8% of those in the HFS groups. Mortality rate among calves in the two treatments was similar as indicated by the fact that 89.3% of the calves born in the LFS groups were weaned compared to 90.1% of those born in the HFS groups. Calving percentage of the LN cows (85.2%) was similar to that of the GN cows (87.9%) and the calf mortality was similar for the two treatments. These data suggest that neither soil F level nor nutritional level, in the range of this experiment, severely affected conception, calving, or mortality rate.

Calf gains. When weaning records of all calves born from 1962 through 1968 were considered, a slight increase (P>.05) in preweaning rate of gain for calves in the LFS groups (Table 18) over that of calves in the HFS groups was observed (1.73 pounds per day compared to 1.62 pounds). Preweaning rate of gain of calves in the LFS-GN and LFS-LN groups were similar (1.75 vs 1.74 pounds per day).

Table 17. The effects of soil F content and nutritional level on the lifetime reproductive performance of cows 8 years old or older[1]

	Cows calving[2]		Calves weaned vs. those born[3]	
	Percent			
Low Fluorine Soil (LFS)	86.5		89.3	
Good Nutrition (GN)		88.2		87.6
Low Nutrition (LN)		84.7		91.0
High Fluorine Soil (HFS)	85.8		90.1	
Good Nutrition (GN)		87.0		93.6
Low Nutrition (LN)		85.5		89.3
Good Nutrition	87.9		89.5	
Low Nutrition	85.2		89.9	

[1]Only cows born between 1958 and 1959, inclusive, and remaining in the respective pastures for 8 to 13 years, were included.

[2]Ratio of the number of cows calving to the number exposed.

[3]Ratio of the number of calves weaned to the number born.

Table 18. Performance of calves of all cows from 1962 through 1968

	No. of calves		ADG birth to weaning	
			Pounds	
Low F Soils (LFS)	163		1.73	
Good nutrition (GN)		77		1.74
Low nutrition (LN)		86		1.75
High F Soil (HFS)	229		1.62	
Good nutrition (GN)		100		1.73
Low nutrition (LN)		129		1.54
All Good nutrition	177		1.73	
All Low nutrition	215		1.64	

However, calves in the GN-HFS groups gained significantly faster ($P < .05$) than calves in the LN-HFS groups.

The preweaning performances of all calves from cows exposed to the respective treatments for 8 to 13 years (those cows born between 1956 and 1959, inclusive) was analyzed separately and is presented in Table 19. A significant effect ($P < .025$) of soil F level on calf performance was observed. Mean adjusted ADG of the 396 calves weaned by these cows between 1958 and 1968 was 1.65 ± .28 pounds per head per day. The ADG of calves in the LFS group was 1.72 pounds per head per day compared to 1.67 pounds for calves in the HFS groups. There was also a significant difference in ADG among years for calves within soil F levels. However, no significant

Table 19. Preweaning performance of all calves of cows[1] exposed to the respective soil F and nutritional levels for 8 years or more

	No. of calves		ADG birth to weaning	
			Pounds	
Low Fluorine Soil (LFS)	175		1.72	
Good Nutrition (GN)	85			1.75
Low Nutrition (LN)	90			1.71
High Fluorine Soil (HFS)	221		1.67	
Good Nutrition (GN)	106			1.75
Low Nutrition (LN)	115			1.59
Good Nutrition		191	1.68	
Low Nutrition		205	1.63	

[1]Only calves from cows born between 1956 and 1961 inclusive, and remaining in the respective pastures for 8 to 13 years, were included.

difference in preweaning performance was attributable to nutritional level (1.63 vs 1.68 pounds per day for LN and GN calves, respectively).

It appears that the effects of high soil fluorine (>1500 ppm) are not detectable in young (2 to 5 years old) cows. However, these effects may be expressed after prolonged ingestion (8 to 10 years) of forage produced on high F soils.

Concentration Of Fluorine In Bone

When this experiment was terminated in 1969, bone samples were obtained from each animal. Samples from the right metacarpal (RMC), mandible (MAND), tail vertebrae (TAIL), 9th rib, 10th rib, and right metatarsal were analyzed for F content. The effects of soil F and nutritional level on the F content of these bone samples are shown in Table 20. Since age of the animals varied, age was held constant in the statistical model and the means presented in Table 20 are age-constant values. Coefficients of correlation, presented in Table 21, reflect the highly significant ($P < .001$) relationship between F content of various bones. These high coefficients of correlation indicate that samples from any of these bones would reflect the status of F accumulation in the skeletal structure of similar-aged animals.

Throughout the experiment, bone samples were collected from the RMC of each animal that died or was removed from the experiment, including calves that were dead at birth. The mean F content of RMC samples from calves that died between birth and weaning are shown in Table 22 by soil F, nutritional level, and age. These means indicate that age of the animal significantly influenced bone F content.

Soil F level, nutritional level, age of the animal, and the inter-

Table 20. Fluorine content[a] of bone[b] samples of animals on the respective treatments in 1969

	RMC	Mand	Tail	9th Rib	10th Rib	RMT
	Parts per million					
LFS	3253	3730	3721	3659	3772	3154
HFS	5540	6089	6188	6207	6321	5434
LN	4674	5200	5214	5184	5412	4590
GN	4118	4620	4695	4681	4681	3998
LFS-LN	3601	4025	4018	3980	4155	3493
LFS-GN	2905	3437	3424	3338	3889	2815
HFS-LN	5748	6377	6411	6389	6670	5687
HFS-GN	5331	5803	5965	6025	5973	5181

[a]These values were adjusted to an age-constant basis.

[b]RMC = Right Metacarpal
Mand = Mandible
RMT = Right Metatarsal

Table 21. Correlation between F contents of various bones[a]

	RMC	Mand	9th Rib	10th Rib	Tail	RMT
RMC	1.00	0.90	0.86	0.90	0.93	0.93
Mand		1.00	0.92	0.92	0.92	0.87
9th Rib			1.00	0.96	0.93	0.86
10th Rib				1.00	0.93	0.87
Tail					1.00	0.88
RMT						1.00

[a]RMC = Right metacarpal
Mand = Mandible
RMT = Right Metatarsal

action of soil F and nutritional level were included in a statistical model to evaluate the effects of these factors on the F content of the RMC of all animals grazing the respective pastures. Age of the

Table 22. Fluorine content of calf right metacarpal bones

Group	Days of age 0	1-50	51-90	91-200	200-300
	F (ppm)				
1	180(5)[a]	177(2)	209(8)	434(2)	456(2)
2	——	255(3)	241(2)	271(1)	648(2)
5	166(2)	265(1)	246(8)	326(1)	884(2)
AVG[b]	176(7)	231(6)	229(18)	366(4)	663(6)
3	422(2)	——	631(3)	——	1538(2)
4	463(3)	438(3)	538(4)	——	1740(3)
6	315(7)	380(8)	305(11)	——	766(2)
7	438(6)	——	265(6)	361(3)	1305(3)
AVG[b]	393(18)	396(11)	375(24)	361(3)	1374(10)

[a]Numbers in parentheses are the number of samples included in the average.
[b]Weighted mean within LFS and HFS Groups.

animals included in this analysis varied from 0 days to 13 years. Overall least-square means from this analysis are given in Table 23, and suggest that both soil F content and age of the animal had a significant effect on F content of the RMC. It should be noted that age, in this study, reflects the length of exposure to the F levels. The absence of a significant interaction between soil F and nutritional level indicated that the effect of nutritional level was similar in both HFS and LFS groups. The analysis of variance shown in Table 24 indicates that 28.7% of the variation in F content was due to soil F level and an additional 58.2% was due to the linear term of the age polynomial. Nutritional level did not significantly affect the F content of the RMC. The two factors, soil F level and age of the animal, accounted for about 99% of the variation in bone F level.

Table 23. Factors affecting F content of right metacarpal bone[a]

Factor	Mean RMC F content
Soil F Level	ppm
Low	1715
High	3212
Nutritional Level	
Low	2461
Good	2465
Regression of RMC F content on age[b]	
Linear	28.86
Quadratic	-0.25

[a]All samples collected between 1961 and 1969, inclusive.
[b]Age of the animals ranged from 0 days to 13 years.

Soil F content. The mean F content of the RMC of cows in the HFS groups in 1969 (Table 20) was 70% greater than that of the LFS

Table 24. Analysis of variance of right metacarpal F content (all samples)

Source	df	Mean square	F
Soil F Level	1	1195405.95	104
Nutritional Level	1	7.92	<1
Age, Linear	1	2422273.19	210
Age, Quadratic	1	533085.32	46
Remainder	214	11532.54	

cows (3253 vs 5540 ppm). This difference was similar regardless of nutritional level.

Nutritional level. The F content of bone samples from the LN cows in 1969 was approximately 13% higher than that of the GN cows. However, when all samples collected during the 7 years were considered, this effect of nutritional level appeared to be smaller. The effect of nutritional level on bone F content was not statistically significant in either analysis.

Age. The accumulated F content in bones of older cattle compared to that in young animals was highly significant and appeared to be curvilinear. In order to evaluate the rate of accumulation of F in the bone of the HFS and LFS cattle, a separate regression analysis was performed for each group. Since nutritional level did not appear to affect F accumulation, this factor was not included in these analyses. Results of the two analyses are presented in Figure 5. These curves show that the rate of F accumulation was higher in HFS cows than in LFS cows. The Y-intercepts of the two equations represent the estimated F content of calves at birth and were similar to the values presented in Table 22. The difference in magnitude of the F content in both cases indicates that soil F level influenced the rate of accumulation of F in the bones of the unborn calf.

The curves presented in Figure 5 suggest that the rate of accumulation tends to decrease at an earlier age in the LFS cattle than in the HFS cattle. These results support other reports in the literature which suggest that accumulation of F in bone depends not only upon the source of F ingested, but also upon the concentrations of F in the feed and the period of time over which such ingestion occurs.

Gross hyperplasia of cow bones. The metacarpals, metatarsals, mandibles, and ribs (6th through 12th) of all cows slaughtered in 1969 were scored subjectively for degree of gross hyperplasia. In general, the index score for HFS cattle was slightly higher than that for LFS cattle with respect to gross hyperplasia of the right metacarpal (RMC), left metacarpal (LMC), right metatarsal (RMT), left metatarsal (LMT), left ramus, and for the ribs. However, the index score for HFS cattle was not significantly different from that for the LFS cattle. Cattle in Group 3 had higher index scores for RMC, LMC,

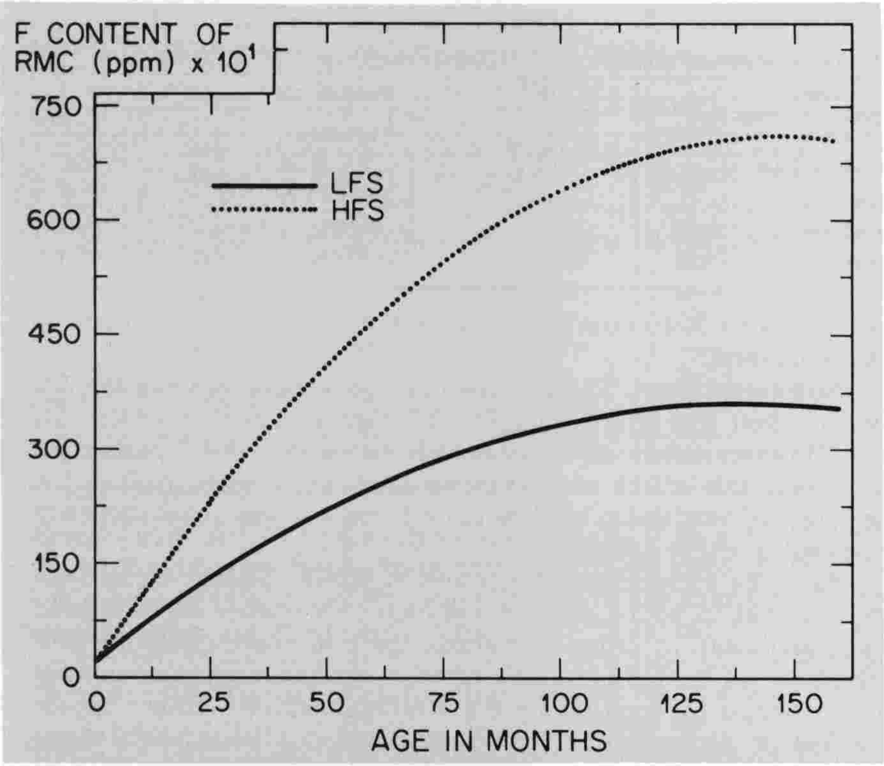

Figure 5. **Relationship of fluorine content of the right metacarpal with age of beef cows grazing pastures grown on soils low (<1000 ppm) and high (>2000 ppm) in fluorine content.**

RMT, LMT, and ribs than the other HFS groups. This was probably due to the higher soil and forage F content for that pasture (Tables 5 and 6).

F Content Of Urine And Hair

Urinary fluorine. Mean F concentration and specific gravity of urine samples from the various group of cows at the four collection periods are shown in Table 25. Differences in urinary F concentrations on the different dates were significant ($P < .05$). These variations may have been due to differences in time of collection, time elapsed since last grazing, seasonal differences, or undetermined factors.

The increased urinary F concentration for cattle grazing HFS pastures compared to those grazing LFS pastures was significant in 1968. In general, F concentration in the urine of cows in the HFS-GN groups was higher than that of the other groups. A slight increase in urinary F concentration was noted for GN cows compared to LN cows in the LFS groups. Merriman and Hobbs (1962) reported a

Table 25. Concentration of fluorine in composited urine samples

Treatment	Group No.	July 1961 Specific gravity	July 1961 PPM F	July 1967 Specific gravity	July 1967 PPM F	August 1968 Specific gravity	August 1968 PPM F	November 1968 Specific gravity	November 1968 PPM F	Avg. 1961-1968 PPM F	Avg. 1961-1968 C.V. %
LFS+GN	1	1.011	1.04	1.025	2.20	1.017	3.06	1.017	3.91	2.55	48.1
LFS+LN	2	1.015	1.60	1.013	1.04	1.026	2.51	1.019	2.78	1.98	40.7
LFS+LN	5	1.016	1.33	1.010	0.60	1.025	4.10	1.025	6.88	3.23	88.6
LFS	AVG	1.014	1.32	1.016	1.28	1.023	3.22	1.020	4.52	2.59	68.1
HFS+GN	3	1.016	3.42	1.018	3.68	1.035	13.16	1.030	9.81	7.52	63.6
HFS+LN	4	1.015	3.35	1.024	3.58	1.036	9.70	1.020	6.32	5.74	51.7
HFS+LN	6	1.015	1.80	1.018	2.75	1.017	3.10	1.021	6.17	3.46	54.7
HFS+GN	7	1.026	2.51	1.010	1.03	1.023	6.45	1.021	10.02	5.00	81.0
HFS	AVG	1.018	2.77	1.018	2.76	1.028	8.10	1.023	8.08	5.43	65.4

slightly higher urinary F value for cows in the LN groups.

The National Research Council (1960) reported that concentrations of less than 10 ppm of F in cattle urine is considered normal. Only twice in this experiment were F concentrations in the group composite urine samples 10 ppm or above. In August 1968, the sample from Group 3 (HFS + LN) contained 13.16 ppm F and in November 1968 the sample for Group 7 (HFS + GN) contained 10.02 ppm.

Fluorine content of cattle hair. Just before termination of the experiment, hair samples were taken from the hip and jaw regions of each cow and were analyzed for F content. Results of these analyses are shown in Table 26. The F contents of the hair samples were not significantly related ($P < .05$) to the amount of F ingested by the animal or to the F accumulation in the bones. In addition, there was no difference in the F content of hair samples taken from the jaw region and those taken from the hip region.

Table 26. Fluorine content of cattle hair

Treatment[a]	Group	Mean F content	
		Jaw	Hip
		Parts per million	
LFS-GN	1	42.7	43.5
LFS-LN	2	22.5	17.0
LFS-LN	5	17.5	19.9
AVG all LFS Groups		27.6	26.8
HFS-GN	3	15.8	27.0
HFS-LN	4	21.4	23.4
HFS-LN	6	33.2	32.2
HFS-GN	7	22.8	28.4
AVG all HFS Groups		23.3	27.8

[a]LFS-Low Fluorine Soil (< 800 ppm).
HFS-High Fluorine Soil (> 1500 ppm).
GN-Good nutrition (adequate pasture).
LN-Low nutrition (short pasture).

Teeth

Incisors. The index of all incisor teeth ranged from 1.8 to 3.2 for cattle on HFS (Table 27). These corresponded with indexes of incisor teeth condition for cattle fed by Hobbs et al. (1954) at feed levels of 10 to 20 ppm F from NaF added to the normal ration. The indexes of all incisor teeth ranged from 0.0 to 0.6 for cattle on LFS. The increase in index of incisor teeth condition for HFS cattle compared to LFS cattle was highly significant ($P < 0.01$) for all pairs of incisors considered together or for any one group of pairs, such as corners.

The average classifications of the lateral and corner incisor teeth of the animals in both the LFS and HFS groups were higher than the classification of the central and intermediate teeth.

The effects of age, soil fluorine level, and nutritional level on the average classification of all incisor teeth are shown in Figure 6. Average classification tended to increase as age of cow increased from 2 to 4 years of age. This increase was greater in cattle grazing HFS pastures than in those grazing LFS pastures; it appeared due to the fact that the lateral and corner incisors have a greater pre-eruption exposure to F and thus show more lesions than centrals and intermediates. After 4 years of age, the average classification tended to decrease in all groups; however, the rate of decline was greater in the HFS groups. This significant decline in average incisor classification of the HFS cattle was probably due to the wearing away of certain lesions used in determining classifications.

Table 27. Classification of incisor teeth and index of incisor teeth condition

Treatment	Group No.	Index of incisor teeth condition					Classification range
		Centrals	Intermediates	Laterals	Corners	Avg.	
LFS+GN	1	0.0[b]	0.2[b]	0.4[c]	0.6[c]	0.3	1A-3
LFS+LN	2	0.0[b]	0.5[b]	1.1[c]	1.0[c]	0.6	1A-5A
LFS+LN	5	0.1[b]	0.2[b]	0.4[c]	0.5[c]	0.3	1A-2
Avg LFS (groups 1, 2, 5)		0.0	0.3	0.6	0.7	0.4	1A-5A
HFS+GN	3	1.5[b]	3.0[c]	3.5[c]	4.6[d]	3.2	1A-5C
HFS+LN	4	0.6[b]	1.9[c]	3.4[d]	4.9[e]	2.7	1A-5C
HFS+LN	6	0.5[b]	1.2[c]	2.5[d]	3.4[e]	1.9	1A-5C
HFS+GN	7	0.5[b]	1.0[c]	2.3[d]	3.3[e]	1.8	1A-5C
Avg HFS (groups 3, 4, 6, 7)[f]		0.8	1.8	2.9	4.0	2.4	1A-5C

[a]Index of incisor teeth condition was calculated by taking an unweighted average of the average classification for each group.

[b, c, d, e]Means in the same row superscripted with different letters are significantly different ($P < .05$).

[f]Mean index of each HFS group was significantly greater than that of all LFS groups.

Figures 7 through 10 are pictures of incisor teeth of animals born between 1956 and 1959 and raised (except for a period from weaning until the following spring, when in a small pasture on the farm) in pasture groups representing each of the four combinations of soil fluorine levels and nutritional levels (HFS-GN, HFS-LN, LFS-GN, and LFS-LN). These pictures represent the average teeth conditions of the animals in each group at young and later ages and portray the influence of age, nutritional level, and soil fluorine level on various incisor teeth. Description of the incisor teeth of these animals accompany the pictures.

The reader may wish to study the examples of several classifications in order to understand the nomenclature of the Tennessee system for incisor teeth (Table 2). In Figure 8, the fourth tooth from the right is the left central incisor. The centrals erupt when the animal is about 1½ to 2 years of age and the average bone F content of the animal represented here was 1000 to 2000 ppm. The left intermediate incisor is the third tooth from the right. This pair usually

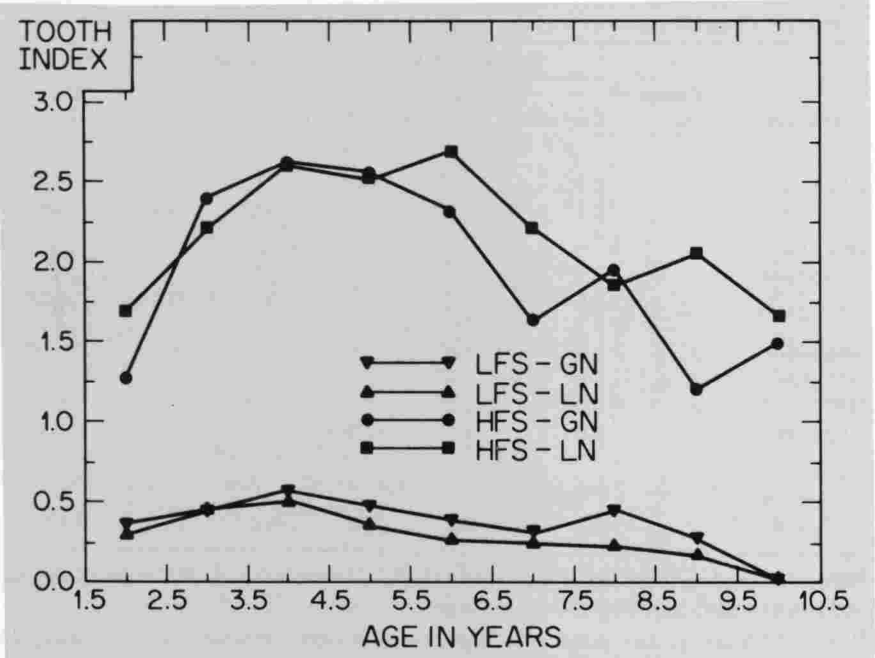

Figure 6. Effect of age, soil fluorine level, and nutritional level on indices of incisor teeth condition.

erupts when the animal is 2 to 2½ years old. The second tooth from the right is the left lateral, and the laterals generally erupt when cattle are about 3 years of age. On the extreme right is the left corner incisor. This pair usually erupts when the animal is 3½ to 4 years old and the average bone F content of the animal represented here was 3000 to 6000 ppm. There are often wide variations in times (6 months or more) of eruptions either for pairs or individual teeth.

Figure 7. Teeth changes of cow number 137 on Treatment 1 (LFS-GN). A = 2 years old. B = 3 years old. C = 4 years old. D = 9 years old.

DESCRIPTIONS AND PICTURES
TREATMENT NO. 1 (LFS, GN)

ANIMAL NO. 137

Two Years Old (Figure 7A)

CENTRALS: *Luster*—good; *Chalkiness*—medium focal; *Stain*—medium vegetative; *Wear*—normal; *Other*—chipped cap on right; *Classification*—1B.

INTERMEDIATES: Temporary.

LATERALS: Temporary.

CORNERS: Temporary

PREMOLARS AND MOLARS: First, second, and third pairs: Temporary. Fourth and fifth pairs: Normal wear and stain. Sixth pairs: Not in.

Three Years Old (Figure 7B)

CENTRALS: *Luster*—good; *Stain*—medium vegetative; *Wear*—normal; *Classification*—1A.

INTERMEDIATES: *Luster*—good; *Stain*—medium vegetative; *Wear*—normal; *Classification*—1A.

LATERALS: *Luster*—good; *Stain*—medium vegetative and slight discoloration; *Chalkiness*—medium focal; *Wear*—normal; *Classification*—1B.

CORNERS: Temporary.

PREMOLARS AND MOLARS: Third pair erupting and sixth pair concealed by feed. All others; Normal wear and stain.

Four Years Old (Figure 7C)

CENTRALS: *Luster*—good; *Stain*—slight vegetative; *Wear*—normal; *Classification*—1A.

INTERMEDIATES: *Luster*—good; *Stain*—slight vegetative; *Wear*—normal; *Classification*—1A.

LATERALS: *Luster*—good; *Stain*—slight, light-brown; *Wear*—normal; *Classification*—2.

CORNERS: *Luster*—fair; *Stain*—slight, light-brown; *Chalkiness*—heavy focal; *Wear*—normal; *Classification*—2.

PREMOLARS AND MOLARS: First through fifth pairs: Normal wear and stain. Sixth pair: In about one-half.

Nine Years Old (Figure 7D)

CENTRALS: *Luster*—good; *Wear*—normal; *Classification*—1A.

INTERMEDIATES: *Luster*—good; *Wear*—normal; *Classification*—1A.

LATERALS: *Luster*—good; *Wear*—normal; *Classification*—1A.

CORNERS: *Luster*—good; *Wear*—normal; *Classification*—1A.

PREMOLARS AND MOLARS: All normal for wear and stain except for suspected staining on lower three and uneven wear on upper five.

Figure 8. Teeth changes of cow number 27 on Treatment 2 (LFS-LN). A = 2 years old. B = 3 years old. C = 7 years old. D = 10 years old.

DESCRIPTIONS AND PICTURES
TREATMENT NO. 2 (LFS, LN)

ANIMAL NO. 27

Two Years Old (Figure 8A)

CENTRALS: *Luster*—good; *Stain*—slight vegetative; *Wear*—normal; *Classification*—1A.

INTERMEDIATES: Temporary.

LATERALS: Temporary.

CORNERS: Temporary.

PREMOLARS AND MOLARS: First, second, and third pairs: Temporary. Fourth and fifth pairs: Normal wear and stain. Sixth pairs: Lowers not in and uppers erupting.

Three Years Old (Figure 8B)

CENTRALS: *Luster*—good; *Stain*—slight vegetative; *Wear*—normal; *Classification*—1A.

INTERMEDIATES: *Luster*—good; *Stain*—slight vegetative; *Wear*—normal; *Classification*—1A.

LATERALS: *Luster*—good; *Stain*—slight vegetative; *Chalkiness*—slight; *Wear*—normal; *Classification*—1A.

CORNERS: Left temporary and right erupting.

PREMOLARS AND MOLARS: Normal wear and stain. Lower sixth pair in three-fourths.

Seven Years Old (Figure 8C)

CENTRALS: *Luster*—good; *Stain*—slight focal vegetative; *Wear*—normal; *Classification*—1A.

INTERMEDIATES: *Luster*—good; *Stain*—slight vegetative; *Wear*—normal; *Classification*—1A.

LATERALS: *Luster*—good; *Wear*—normal; *Classification*—1A.

CORNERS: *Luster*—good; *Stain*—slight vegetative on left only; *Wear*—normal; *Classification*—1A.

PREMOLARS AND MOLARS: Normal wear and stain on first, third, fifth, and sixth pairs. Second and fourth pairs normal wear with light-brown stain on upper two and upper left four.

Ten Years Old (Figure 8D)

CENTRALS: *Luster*—good; *Wear*—slight and uneven; *Classification*—1A.

INTERMEDIATES: *Luster*—good; *Wear*—slight and uneven; *Classification*—1A.

LATERALS: *Luster*—good; *Wear*—normal to slight and uneven; *Classification*—1A.

CORNERS: *Luster*—good; *Wear*—normal; *Classification*—1A.

PREMOLARS AND MOLARS: Normal wear and stain.

A C

B D

Figure 9. Teeth changes of cow number 18-8 on Treatment 3 (HFS-GN). A = 2 years old. B = 3 years old. C = 8 years old. D = 11 years old.

DESCRIPTIONS AND PICTURES
TREATMENT NO. 3 (LFS, GN)

ANIMAL NO. 18-8

Two Years Old (Figure 9A)

CENTRALS: *Luster*—poor to fair; *Stain*—slight and light-brown; *Chalkiness*—heavy cross; *Wear*—normal; *Classification*—2.

INTERMEDIATES: Temporary.

LATERALS: Temporary.

CORNERS: Temporary.

PREMOLARS AND MOLARS: First, Second, and Third pairs: Temporary or erupting; Fourth and Fifth pairs: Normal wear and stain; Sixth pairs: Uppers not in, lowers have slight wear and medium stain.

Three Years Old (Figure 9B)

CENTRALS: *Luster*—fair to good; *Stain*—slight discoloration and slight vegetative; *Wear*—normal; *Classification*—1B.

INTERMEDIATES: *Luster*—fair; *Stain*—excessive, light, diffuse, and focal; *Wear*—normal; *Classification*—2.

LATERALS: *Luster*—fair; *Enamel hypoplasia*—medium to heavy, pit; *Tooth hypoplasia*—suspected; *Wear*—slight; *Classification*—5B.

CORNERS: Right is temporary and left still erupting.

PREMOLARS AND MOLARS: First, Fourth, and Fifth pairs: Normal wear; Second pairs: Normal wear on uppers, slight to medium wear on lowers; Third pairs: Normal wear on uppers and slight on lowers; Sixth pairs: Uppers have medium wear and lowers normal wear.

Eight Years Old (Figure 9C)

CENTRALS: *Luster*—good; *Wear*—normal; *Classification*—1A.

INTERMEDIATES: *Luster*—good; *Stain*—medium; *Wear*—normal to slight *Classification*—1.

LATERALS: *Luster*—good; *Stain*—medium and light-brown; *Wear*—slight *Classification*—2.

CORNERS: *Luster*—poor; *Stain*—excessive; *Enamel hypoplasia*—suspected to slight; *Classification*—4 (right) and 5A (left).

PREMOLARS AND MOLARS: First pairs: Normal wear on all; Second pairs: Heavy wear; Third pairs: Wear heavy on uppers and medium on lowers; Fourth pairs: Wear normal; Fifth pairs: Wear normal; Sixth pairs: Wear is excessive on uppers and slight on lowers.

Eleven Years Old (Figure 9D)

CENTRALS: *Luster*—good; *Chalkiness*—medium focal; *Wear*—normal but uneven; *Classification*—1B.

INTERMEDIATES: *Luster*—good; *Stain*—medium; *Wear*—slight and uneven *Classification*—2.

LATERALS: *Luster*—good; *Stain*—medium; *Wear*—medium and uneven; *Classification*—2.

CORNERS: *Luster*—poor; *Enamel hypoplasia*—suspected on right and medium to heavy on left; *Wear*—medium to heavy; *Classification*—4 (right) and 5B (left).

PREMOLARS AND MOLARS: First pairs: Normal wear, but uppers slightly long; Second pairs: Wear is medium (uppers) and heavy to excessive and uneven (lowers); Third pairs: Slight (lower) to medium (upper) wear; Fourth pairs: Normal wear; Fifth pairs: Normal (upper) to slight (lower) wear and uppers slightly long posteriorly; Sixth pairs: Wear is heavy to excessive on uppers and slight and uneven on lowers.

Figure 10. Teeth changes of cow number 87 on Treatment 4 (HFS-LN). A = 2 years old. B = 3 years old. C = 4 years old. D = 10 years old.

DESCRIPTIONS AND PICTURES
TREATMENT NO. 4 (HFS, LN)

ANIMAL NO. 87

Two Years Old (Figure 10A)

CENTRALS: *Luster*—fair; *Stain*—medium to heavy; *Wear*—normal; *Classification*—2.

INTERMEDIATES: Temporary.

LATERALS: Temporary.

CORNERS: Temporary.

PREMOLARS AND MOLARS: First, Second, and Third pairs: Temporary or erupting; Fourth pairs: Normal wear; upper has heavy brown stain; Fifth and Sixth pairs: No reading.

Three Years Old (Figure 10B)

CENTRALS: *Luster*—fair; *Stain*—slight; *Chalkiness*—heavy cross and focal; *Wear*—normal; *Classification*—2.

INTERMEDIATES: *Luster*—poor; *Stain*—heavy; *Chalkiness*—excessive and diffuse; *Caries*—pinpoint foci; *Wear*—normal to slight; *Classification*—3.

LATERALS: *Luster*—poor; *Chalkiness*—diffuse; *Enamel hypoplasia*—suspected (right) to slight (left); *Wear*—slight to medium; *Classification*—4 (right) and 5A (left).

CORNERS: *Luster*—poor; *Enamel hypoplasia*—heavy, pit type; *Tooth hypoplasia*—suspected; *Wear*—slight; *Other*—still erupting; *Classification*—5B.

PREMOLARS AND MOLARS: First pairs: Slightly long above; otherwise normal wear; Second pairs: Slight to medium wear above with normal wear below; Third pairs: Erupting; Fourth pairs: Uppers are medium long while lowers have normal wear; Fifth pairs: Normal wear.

Four Years Old (Figure 10C)

CENTRALS: *Luster*—good; *Stain*—slight discoloration to slight brown; *Chalkiness*—medium focal; *Wear*—normal; *Classification*—1B to 2.

INTERMEDIATES: *Luster*—poor; *Stain*—heavy, brown; *Enamel hypoplasia*—suspected to slight; *Wear*—slight; *Classification*—4.

LATERALS: *Luster*—fair; *Stain*—medium brown; *Enamel hypoplasia*—suspected to slight; *Wear*—medium; *Classification*—4 to 5A.

CORNERS: *Luster*—poor; *Enamel hypoplasia*—Excessive pit and thinned enamel; *Wear*—medium; *Classification*—5C.

PREMOLARS AND MOLARS: First pairs: Slight wear on lower right with normal wear on others; Second pairs: Heavy to excessive wear on uppers with normal wear on lowers; Third pairs: Upper left temporary and upper right has heavy wear while lowers have slight to medium wear; Fourth pairs: Upper left has slight wear; Sixth pairs: Uppers have excessive wear anteriorly.

Ten Years Old (Figure 10D)

CENTRALS: Left is missing. *Luster*—good; *Wear*—normal; *Classification*—1A.

INTERMEDIATES: *Luster*—fair; *Stain*—excessive; *Enamel hypoplasia*—suspected to slight; *Wear*—medium; *Classification*—4.

LATERALS: *Luster*—poor, *Enamel hypoplasia*—heavy to excessive; *Wear*—excessive (left) heavy (right); *Classification*—5C (left) 5B (right).

CORNERS: *Luster*—poor; *Enamel hypoplasia*—heavy to excessive; *Wear*—excessive (left), heavy (right); *Classification*—5C (left) 5B (right).

PREMOLARS AND MOLARS: First pairs: Normal wear on uppers with slight wear on lowers; Second and Third pairs: Excessive wear; Fourth and Fifth pairs: Normal wear; Sixth pairs: Excessive wear.

Deaths, Accidents, And General Health

Incidence of illnesses, accidents, and deaths during the experimental period, 1962 to 1968, are shown in Table 28 for both cows and calves. Most diagnoses reported are those made by the local veterinarian.

The ratio of the incidence of illnesses to the number of cows and calves in the various groups indicated that soil F level did not affect the general health of these animals. Of the 33 calves that died prior to 1 week of age, 13 were from the LFS groups and 20 from the HFS groups. Similar numbers of calves from the LFS and HFS groups (5 and 6) died after 7 days of age. Dystocia and exposure accounted for most of these calf deaths. The arrangement of the herds at calving time, necessitated by the experiment, made it difficult for the herdsman to give close supervision at calving.

Six cows in the LFS groups died during the 8-year period compared to 13 in the HFS groups. However, the average age of the cows in the HFS groups was greater than that of the LFS groups in the later years. For all treatments 10 cows aborted, and 13 incidences of everted uterus, 3 lameness, 2 stiffness, 5 grass tetany, 8 cancer eye, and 1 case of hardware disease were observed.

Table 28. Accidents, illness, and deaths, 1961-1968

Groups	Low fluorine soil 1	2	5	Total	High fluorine soil 3	4	6	7	Total
CALVES									
Abnormal or weak	0	0	0	0	0	0	0	1	1
Aborted or premature	4	1	0	5	1	2	2	0	5
Blind	0	0	0	0	0	0	0	1	1
Bloat	0	0	0	0	1	0	0	1	2
Blackleg	1	0	0	1	0	0	0	0	0
Dead (0-7 days)	10	0	3	13	1	2	11	6	20
Dead (7 + days)	1	2	2	5	0	2	4	0	6
Dwarf	0	0	0	0	0	0	0	0	0
Navel infection	0	0	0	0	0	0	0	0	0
Pneumonia	0	2	0	2	1	0	0	0	1
Scours	0	0	1	1	1	0	2	0	3
Sick	0	0	0	0	0	0	1	1	2
COWS									
Bloat	0	0	0	0	0	0	0	0	0
Calving injury	0	0	0	0	0	0	1	0	1
Cancer eye	3	3	0	6	1	0	1	0	2
Deaths	1	2	3	6	3	3	2	5	13
Diarrhea	0	0	1	1	0	0	1	0	1
Dystocia	0	0	0	0	1	0	2	0	3
Everted rectum	0	0	0	0	0	0	1	0	1
Everted uterus	0	1	0	1	1	1	5	0	7
Lameness	1	0	0	1	0	0	2	0	2
Mastitis	0	0	0	0	0	0	0	0	0
Mummified fetus	0	0	0	0	0	0	0	0	0
Pink eye	0	0	0	0	0	0	0	0	0
Retained placenta	0	0	0	0	0	0	0	0	0
Rhinitis	0	0	0	0	0	0	0	0	0
Stiffness	1	0	0	1	0	0	1	0	1
Unthrifty	0	0	0	0	0	0	1	0	1
Vaginitis	0	0	1	1	0	0	0	0	0
Pneumonia	0	0	0	0	0	0	0	0	0
Grass tetany	0	0	2	2	0	0	0	3	3
Hardware disease	0	0	0	0	0	1	0	0	1
Cows and calves									
Footrot	1	0	1	2	0	0	2	0	2

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