GRAZING COW AND CALF RESPONSES TO ZINC SUPPLEMENTATION[1]

H. F. Mayland[2], R. C. Rosenau and A. R. Florence[3]

US Department of Agriculture, Kimberly, ID 83341[4]

Summary

This experiment evaluated weight gain responses to supplemental Zn by cows and calves grazing forage containing less than 20 ppm Zn. One hundred cow-calf pairs in each of 2 years and 120 pairs in a third year were pastured together over a 63- to 77-day preliminary period during which cows were exposed to bulls. Each experimental period began in mid-June after bulls were removed and continued for 125 to 154 days. During this period, cattle grazed mature dry forage containing <20 ppm Zn and were fed protein supplements with or without added Zn. Estimated Zn intake by each cow-calf pair in the control group ranged from about 140 to 260 mg/pair/day. Daily Zn intake was supplied by forage (100 to 200 mg), basal supplement (32 to 57 mg), water (4 mg), iodized block salt (1 mg) and soil (1 mg). Each cow-calf pair fed the supplement with added Zn received an additional 860 to 900 mg Zn/day. Calves fed Zn gained 6% more ($P<.05$) weight (.04 kg/day) than did calves in the control group. Weight gains by cows did not differ ($P<.05$) between the two groups. Clinical signs of Zn deficiency were not observed in any animals. Conception, which occurred before the experimental period, and subsequent calving rates were not affected by Zn supplementation.

(Key Words: *Bromus tectorum*, *Agropyron desertorum*, Beef Cattle, Forage Minerals, Zinc.)

Introduction

Zn deficiency in cattle, especially calves, has been produced experimentally with semipurified or purified diets (Blackmon *et al.*, 1967; Mills *et al.*, 1967). From these studies, researchers concluded that the Zn requirement for young calves was not more than 8 to 12 ppm. However, ruminants have exhibited signs of Zn deficiency when grazing forage containing 20 to 30 ppm Zn (Legg and Sears, 1960; Pierson, 1966; Papasteriadis, 1973; Spais and Papasteriadis, 1973).

Murray *et al.* (1978) reported that Zn concentrations in grasses of southern Idaho rarely exceed 30 ppm and are often below 20 ppm, especially after grasses matured. The present study compared weight gains of calves and cows grazing this forage with gains of animals fed supplementary Zn.

Experimental Procedure

One hundred cow-calf pairs in both 1974 and 1975 and 120 pairs in 1976 were grazed on crested wheatgrass (*Agropyron desertorum* [Fisch. ex Link] Schult.) from early April until mid-June on the Saylor Creek Experimental Range in south central Idaho. During this preliminary period, cows were exposed to bulls. Fifty of the cattle in 1974 and all in 1975 and 1976 were provided by two Hereford breeders. Some, but not all, of the same cows were used in successive years. No attempt was made to measure carryover effects of treatments. In 1974 two other livestockmen each provided 25 Hereford pairs and some Angus × Hereford cows and their Hereford- or Charolais-sired calves. Cows used in the study were 4 to 12 years old and were nursing at least their second calf. Average calving date was February 15.

Preliminary weights were recorded about 3 days after animals began grazing crested wheatgrass. Animals were shrunk overnight, weighed the next day and returned to pasture. This same procedure was used for subsequent weighings. The experimental period during which ani-

---

[1] The authors acknowledge cooperation of livestock owners, W. L. and L. T. Trail and D. R. Carnahan, Idaho Agr. Ext. Service, and technical assistance of Gary Richardson, Biometrician, SEA, AR.

[2] Soil scientist. Present address: Northern Plains Soil and Water Research Center, SEA-AR, Sidney, MT 59270.

[3] Research technicians.

mals grazed mature dry forage began in mid-June after bulls were removed and continued to October or November. Cow-calf pairs were stratified by owner, calf sex and preliminary (mid-April) calf and cow weights, and assigned to 10 groups. Groups were then randomly assigned to two experimental treatments – grass plus basal supplement and grass plus basal plus Zn supplement – each with five replications. Treatment groups within replications were assigned to adjacent pastures. Animals were weighed during the experimental period at 3-, 6-, 6- and 6-week intervals in 1974; at 7-, 5-, 5- and 5-week intervals in 1975, and at 6-, 6- and 6-week intervals in 1976. Weights and weight gains were analyzed by least-squares analyses of variance with unequal subclass numbers (Harvey, 1960).

Cows received IM injections of 1,500,000 IU of vitamin A, 225,000 IU of vitamin D and 150 IU of vitamin E at the start of each experimental period and at about 3-month intervals thereafter. All cattle were sprayed on weigh days with a toxaphene base solution for fly control and cows received a famphur pour-on at first weighing for grub control. Cattle had free access to iodized block salt during the preliminary and experimental periods. Cows were palpated in November 1974 for determination of pregnancy status. Calving records were available for cows on experiment in 1975 and 1976.

Animals were assigned to 32.4-ha pastures in 1974 and 1975 and moved to other ungrazed pastures at midseason. In 1976, division fences were removed and animals were placed in 64.8-ha pastures for the entire season. Stocking was at a moderate rate (Murray *et al.*, 1978). Forage available during the experimental period was mostly (90 to 95% by mass) cheatgrass (*Bromus tectorum)*, with some Sandberg's bluegrass (*Poa sandbergii* Vasey) and lesser amounts of streambank wheatgrass (*Agropyron riparium* Scribn. and Smith). These grasses, especially cheatgrass and bluegrass, were mature and dry by mid-June (Murray *et al.*, 1978). Cattle were within 1 km of good quality water, which was metered before distribution in plastic pipe and stored in iron tanks or troughs.

The basal supplement (table 1) was formulated to meet anticipated forage mineral deficiencies that had been found in earlier studies (Murray *et al.*, 1978). Serum P (± SD) of yearling cattle on these pastures was 70 ± 10, 60 ± 13 and 56 ± 16 ppm P on June 9, September 1 and October 29, 1965, respectively (R. B. Murray, *personal communication).* Zinc oxide (USP, J. T. Baker lot 418374) designed to provide .9 g of Zn/cow-calf day was mixed with one-half of each batch of basal supplement. Fine, granular NaCl was added during formulation to control intake and to adjust the weight for convenient bagging and feeding. The supplement was provided free choice and distributed every 10 days in 1974 and twice weekly in 1975 and 1976. Grab samples of each supplement were taken at about 2-week intervals for chemical analysis.

Forage samples were collected from each pasture by clipping of individual species at 1 cm stubble height during 1974. Forage mineral data were weighted by relative species mass for calculation of a mineral concentration for all forage present. In 1975 and 1976, 20 forage samples, each representing a composite of all forage from 10 .093-m^2 areas, were clipped at each harvest.

Freshly excreted fecal subsamples were collected at about 2-week intervals, except from August 29 through September 4, 1975, when samples were collected each day. Samples were composited by calf or cow sources within each pasture.

All salt, supplement, forage and fecal samples were dried at 60 C and finely ground. Fecal subsamples were dry ashed at 560 C for 5 hr; the ash was moistened with water and dissolved in 2 ml of concentrated HCl. Solutions were evaporated to dryness, and 25 ml of 2M HNO_3 were added before dilution and analysis. Other samples were digested in a 3:1 mixture of HNO_3:$HClO_4$, and minerals were determined by atomic absorption. P was determined on the same digest by the vanadate-molybdate method (Chapman and Pratt, 1961), S was determined turbidimetrically (Stewart and Porter, 1969) and N was determined by a semimicro Kjeldahl procedure to include NO_3-N (Stewart and Porter, 1969). Data are presented on an oven-dry basis.

Hair samples were clipped successively from the upper right rib cage of all animals each weigh day in 1974. The last set of samples was sonified for 30 sec in an aqueous 1% Prell detergent solution, rinsed exhaustively with deionized water and dried at 60 C. Zn was determined in the HNO_3:$HClO_4$ digest by atomic absorption.

The extractability of Zn in soil from a depth

TABLE 1. FORMULATION, CHEMICAL CONTENT AND ESTIMATED DAILY INTAKE OF SUPPLEMENTS

Ingredient	Internat'l ref. no.	Estimated intake, g/cow-calf/day						
		1974			1975			1976
		6/08 to 7/09	7/09 to 8/17	8/17 to 11/12	6/17 to 8/18	8/18 to 11/07	11/07 to 11/18	6/15 to 10/18
Supplement formulation, as-fed basis								
Barley, grain ground	4-00-526	23	23	23	...	...	...	...
Cottonseed, meal (solv. extd.) 41% CP	5-01-621	...	...	...	...	460	...	...
Soybean seed, meal (solv. extd.) 44% CP	5-20-636	318	318	318	461	...	460	384
NaH_2PO_4		30	30	30	35	35	35	29
Na_2SO_4		10	10	10	9	9	9	8
NaCl		75	120	168	146	146	146	120
Supplement analysis, dry matter basis								
Crude protein, total N × 6.24			155			185		166
P, total			11			15		11
Zn, total in basal supplement			.032			.053		.057
Zn, total in basal + Zn supplement			.930			.912		.950

of 0 to 2 cm was first determined by shaking 10 g of soil in 20 ml of a solution containing .005M DTPA (diethylenetriaminepentaacetic acid), .01M $CaCl_2$ and .1M triethenolamine. Zn solubility was also determined by *in vitro* extraction of soil minerals in rumen fluid (Healy, 1972) to estimate soil Zn availability for grazing animals.

A preliminary study was conducted by the authors in 1973, with 25 cow-calf pairs assigned to the following treatments: grass only, grass plus basal supplement and grass plus basal supplement plus 450 mg Zn/pair/day. Composition of the basal supplement was like that used in June 1974 (table 1).

Samples of venous blood were obtained November 6, 1973, by jugular puncture. Blood was collected into dry, heparinized glass bottles with plastic caps and chilled in ice; plasma was later separated by centrifugation at 3,000 × *g* for 30 minutes. Plasma Zn was determined in a 1:1 plasma:water dilution by atomic adsorption. Zn standards were made up in a 1% dextran solution to match the viscosity of diluted plasma.

Plasma and tissue Zn data were analyzed by analysis of variance and Duncan's multiple range test.

In 1974, eight cows in each treatment were not pregnant at the November palpation. This total included 15 crossbred cows that were in poor condition initially. Analysis of the 1974 cow weight-gain data indicated a possible breed × pregnancy status × treatment interaction. However, there were insufficient data on nonpregnant cows for us to confirm this interaction. Therefore, data from the 1974 nonpregnant pairs were excluded, and an owner-breed variable was included in the analysis to account for breed effects. In 1975, two cows, one in each treatment, failed to calve. One cow died in 1976 and was not included in the analysis.

Results

Animal Performance. Calves fed supplemental Zn gained more ($P<.05$) weight each season (table 2) than calves in the basal group. Average daily calf gains attributed to the supplemental Zn were .05, .03 and .05 kg/day in 1974, 1975 and 1976, respectively. Cow weight gains for the experimental period were not affected by Zn supplementation (table 3).

Steer calves gained more ($P<.05$) than heifer calves (table 4), but both sexes responded similarly to added Zn. An owner × sex interaction ($P<.05$) was apparent in 1975, when steer calves gained 14 kg more than heifer calves in one herd, but only 6 kg more in the other herd. The owner-breed variable accounted for a significant amount of variation in the 1974 calf gains. In the initial analysis (not shown), the owner-breed × treatment interaction was not significant for the 1974 calves.

Weight gains during the 1974 (77-day), 1975 (70-day) and 1976 (63-day) breeding seasons were .79, .74 and .82 kg/day, respectively,

TABLE 2. WEIGHT GAINS OF CALVES GRAZING LOW-Zn FORAGE AND FED A BASAL SUPPLEMENT WITH OR WITHOUT ADDED Zn

Weight measurement	Supplement		
	Basal	Basal + Zn	SE[a]
Initial weight, kg			
18 June 1974	102	101	3.3
17 June 1975	104	104	1.9
15 June 1976	115	114	2.1
Average daily gain during supplementation period, kg/day			
1974 (147 days)	.68	.73[b]	.009
1975 (154 days)	.70	.73[c]	.007
1976 (125 days)	.67	.72[c]	.009

[a] Standard error of the mean.

[b] Different from value for basal-supplemented group ($P<.01$).

[c] Different from value for basal-supplemented group ($P<.05$).

TABLE 3. WEIGHT GAINS OF COWS GRAZING LOW-Zn FORAGE AND FED A BASAL SUPPLEMENT WITH OR WITHOUT ADDED Zn

Weight measurement	Supplement		
	Basal	Basal + Zn	SE[a]
Initial weight, kg			
18 June 1974	393	400	8.1
17 June 1975	439	438	8.8
15 June 1976	432	429	6.5
Average daily gain during supplementation period, kg/day			
1974 (147 days)	.21	.28	.034
1975 (154 days)	.19	.21	.020
1976 (125 days)	.09	.10	.016

[a] Standard error of the mean.

for cows and .69, .74 and .79 kg/day for calves.

Fecal, Hair and Plasma Zn. Fecal Zn levels for calves and cows on the basal treatment were 50 and 40 ppm, respectively, early in the experimental period; levels decreased until August 1, after which they did not change. By early September, fecal Zn values were still higher ($P<.01$) for calves than cows and were higher ($P<.01$) for Zn-supplemented animals than for those on the basal treatment (table 5).

At the end of the 1974 trial, hair Zn concentrations were higher ($P<.01$) for Zn-supplemented animals than for those on the basal treatment (table 5). Hair Zn values did not differ ($P>.10$) between cows and calves.

Blood plasma Zn values in 1973 did not differ ($P>.10$) between cows and calves but were affected ($P<.05$) by diet, being .81, .84 and .89 μg/ml for animals on grass only, grass plus basal supplement, and grass plus basal supplement plus 450 mg Zn/pair/day, respectively.

Dietary Zn. Zn Concentrations were consistently less than 20 ppm throughout the experimental grazing periods (figure 1). Mean Zn concentrations ranged from 17 ppm in June 1975 to 7 ppm in September 1976 but generally were highest in 1975 and lowest in 1974 and 1976. Estimated forage Zn intake ranged from 100 to 200 mg/cow-calf/day, assuming forage dry matter intakes of 10 to 14 kg/cow-calf/-day. The basal supplement provided an average of 32. 53 and 57 mg Zn in 1974, 1975 and 1976, respectively (table 1).

Cow-calf pairs drank a maximum of 70 liters water/day. This water contained .06 ppm Zn, providing up to 4 mg of Zn. Cow-calf pairs consumed 10 to 15 g of iodized block salt daily, which provided less than 1 mg Zn/pair/-day.

Mayland *et al.* (1975) reported that these cows and calves consumed about .5 and .2 kg soil/animal/day, respectively, and suggested that this could be a dietary source of trace minerals. Rumen fluid and DTPA each solubilized about 1 μg Zn/g soil. Because of this low solubility, ingested soil probably provided less than 1 mg Zn/cow-calf/day.

Milk contributed Zn to the diets of calves. From data of Miller (1969) and Schwarz and Kirchgessner (1975b), it may be estimated that milk from control cows contained 4 ppm Zn, whereas that from Zn-supplemented cows contained 5 ppm Zn. A cow producing 8 liters milk/day would have provided 30 or 40 mg Zn, depending on treatment, but this supply would decrease as milk production decreased during the season.

Other Dietary Minerals. N and P levels in forage decreased during the season (figure1). Mean concentration ranges of other forage minerals were as follows: K, .2 to 1.0%; Mg, .06 to .14%; Ca, .3 to .4%; S, .1 to .3%; Na, 60 to 300 ppm; Mn, 50 to 70 ppm; Fe, 60 to 600 ppm, and Cu, 4 to 6 ppm. Except for Fe, the mineral concentrations generally were highest early in the grazing season. The basal supplement provided 8 g K, 1 g Mg, 2 g Ca, 10 mg Mn, 80 mg Fe and 20 mg Cu/cow-calf/day.

Discussion

Green crested wheatgrass forage grazed by

TABLE 4. LEAST-SQUARES ANALYSIS OF VARIANCE FOR EFFECTS OF Zn SUPPLEMENTATION, OWNER, CALF SEX AND AGE ON CALF AND COW WEIGHT GAINS OVER THREE GRAZING SEASONS

	Calves						Cows					
	1974 6/18 to 11/12		1975 6/17 to 11/18		1976 6/15 to 10/18		1974 6/18 to 11/12		1975 6/17 to 11/18		1976 6/15 to 11/18	
Source of variation	df	Mean square	df	Mean square	df	Mean square	df	Mean square	df	Mean square	df	Mean square
Total	83		100		120		83		100		119	
Treatment	1	4,916**	1	2,899*	1	4,042*	1	10,924	1	968	1	144
Owner	5	1,785*[a]	1	892	1	127	5	5,880[a]	1	47	1	32,168**
Sex	1	4,050**	1	11,884**	1	4,781*	. . .	. . .	. . .	. . .	. . .	. . .
Replication	4	167	4	392	4	1,954	4	6,553	4	876	4	2,299
Treatment X owner	. . .	. . .	1	316	1	1,041	. . .	. . .	1	171	1	205
Treatment X sex	1	63	1	61	1	1,565	. . .	. . .	. . .	. . .	. . .	. . .
Owner X sex	. . .	. . .	1	2,380*	1	74	. . .	. . .	. . .	. . .	. . .	. . .
Age	. . .	. . .	1	110	1	1,579	. . .	. . .	. . .	. . .	. . .	. . .
Remainder	70	550	88	564	108	724	72	3,248	92	1,785	111	1,263

[a] Owner X breed source calculated in 1974.

*P<.05.

**P<.01.

TABLE 5. FECAL, HAIR AND PLASMA Zn IN COWS AND CALVES FED A BASAL SUPPLEMENT WITH OR WITHOUT ADDED Zn

	Treatment				
Zn content	Grass only	Basal	Basal + 450 mg Zn	Basal + 900 mg Zn	SE[e]
In feces, µg/g[f]					
Cows		10[a]		43[c]	
Calves		23[b]		69[d]	1.1
In hair, µg/g[g]					
Cows and calves		117[a]		125[b]	2.0
In plasma, µg/ml[h]					
Cows and calves	.81[a]	.84[b]	.89[c]		.014

[e] Standard error of the mean.

[f] Fecal Zn values (August 29 through September 4, 1975) with different superscripts are different ($P<.01$).

[g] Hair Zn values (November 12, 1974) with different superscripts are different ($P<.05$).

[h] Data from preliminary study. Plasma Zn values (November 6, 1973) with different superscripts are different ($P<.05$).

animals during the breeding period contained 12 to 25 ppm Zn, which must have been adequate for reproduction, as evidenced by the 98 and 99% calving percentages in 1975 and 1976, respectively. However, Egan (1972) found that lambing percentage increased in response to supplemental Zn when ewes were fed a diet containing only 13 to 45 ppm Zn. The contrast between his observations and ours may have been due to a difference in availability of dietary Zn, a different requirement for cows *versus* ewes or both. Apgar and Travis (1979) found that pregnant ewes fed a low-Zn diet (<5 *vs* 100 ppm Zn) developed signs of deficiency, although they were able to maintain pregnancy. Birth weight of lambs was not affected by Zn treatment, and 6-week weight gains were confounded by a Zn × twin *versus* singles interaction ($P<.001$).

Perdomo *et al.* (1977) found that apparent digestibility of Zn decreased ($P<.05$) with increasing forage maturity in only one of four tropical grasses containing 21 to 40 ppm Zn. In the present study, forage Zn concentrations were less than 20 ppm Zn. This low quality, mature forage was similar to that described by Papasteriadis (1973), Spais and Papasteriadis (1973) and Legg and Sears (1960), who reported signs of Zn deficiency in some animals. In contrast to those reports, we did not find clinical signs of Zn deficiency (Blackmon *et al.*, 1967; Schwarz and Kirchgessner, 1975a) in any animals.

Stake *et al.* (1973) reported that Zn absorption and retention were reduced when performance in young ruminants was limited by a decreased intake of N and energy. In contrast, Somers and Underwood (1969) found that Zn deficiency impaired absorption of S and N. Thus, a complementary relationship appears to exist between N and Zn. The basal supplement used in the present study was formulated to minimize N deficiency.

Zn absorption by nonruminants is reduced in the presence of high Ca and phytic acid, which is found in rich supply in seeds of legumes (e.g., peas and soybeans). However, Zn absorption is not reduced when ruminants are fed diets containing soybean meal and 1.5% Ca (Mills *et al.*, 1967; Kincaid, 1979). Weight gain response to Zn supplementation in the present study was similar when either soybean meal or cottonseed meal was fed (tables 1 and 2). High levels of inorganic Ca (.5 to 2%) may reduce plasma Zn (Perry *et al.*, 1968) and increase fecal Zn (Suttle and Field, 1970), bu these reports are not consistent with those cite earlier.

The mean plasma Zn values of .81 to .8 µg/ml, (table 5) measured in this study are a the low end of the range, .8 to 1.2 µg/ml, de cribed by Mills *et al.* (1967). They are als slightly lower than median plasma Zn leve measured in grazing cattle, some of which h clinical signs of Zn deficiency (Spais a Papasteriadis, 1973). However, signs of

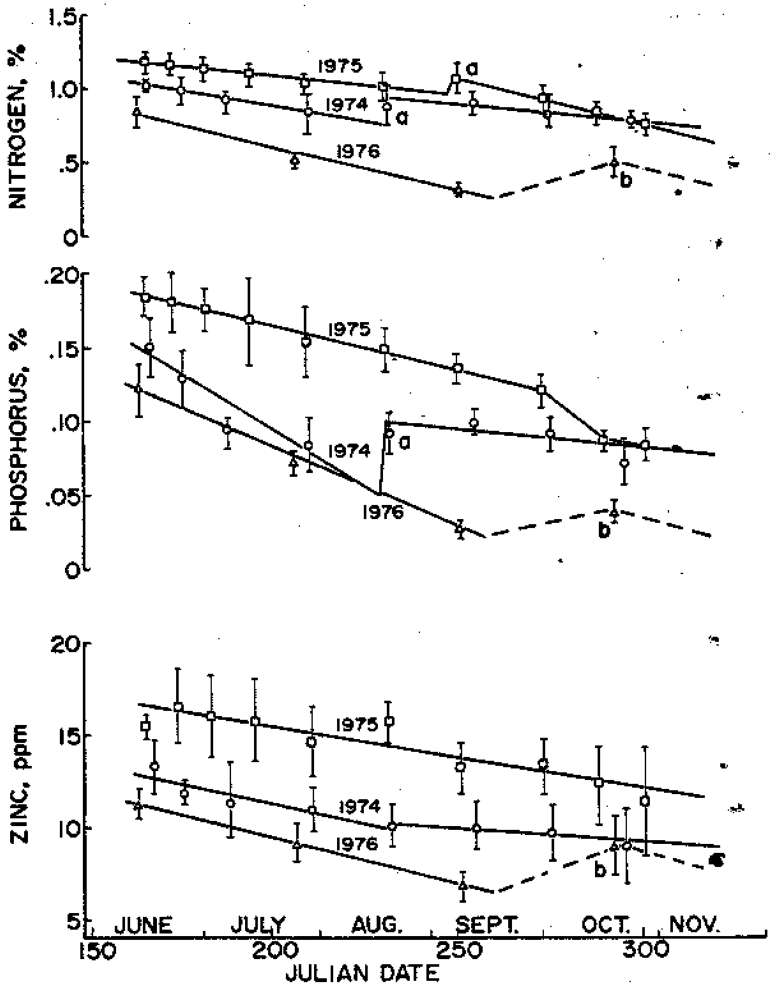

Figure 1. N, P and Zn concentrations in forage during each of 3 years. Data are plotted as the mean of 20 samples ± SD for each sampling date. a-The vertical displacement of some curves coincides with the movement (Aug. 20, 1974; Sept. 2, 1975) of animals to pastures previously ungrazed that season. b-Dashed line indicates a period of fall regrowth.

deficiency were not observed in the Idaho animals.

The hair Zn values of 117 and 125 ppm reported in this study are intermediate to values of 86 ppm Zn in Zn-deficient calves and 129 ppm Zn in Zn-adequate calves (Miller, 1969). From the reports of Miller (1969), Mills *et al.* (1967) and Beeson *et al.* (1977), as well as data in this study, it appears that hair and plasma Zn values are not useful in diagnosing subclinical Zn deficiencies in cattle. Perhaps liver levels of metallothionein would serve more satisfactorily as an indicator of metabolic Zn status (Whanger *et al.*, 1979).

Mills *et al.* (1967) reported that supplements providing .2 mg Zn/kg body weight/day were sufficient to maintain good growth rates in calves, but insufficient to prevent a decrease in plasma Zn. In our study, estimated Zn intake ranged from about .2 to .5 mg/kg body weight for cow-calf pairs in the control group and was about 1.8 mg/kg body weight for those in the Zn-supplemented group. However, a dietary level of .5 mg Zn/kg body weight may not be high enough for practical diets, because Zn-supplemented animals gained more weight than animals in the control group.

The low levels of forage Zn measured in this study do not in themselves explain the animal response to supplementary Zn. Some factors, such as increased fiber fractions in dry forage (Murray *et al.*, 1978), may reduce the availability of Zn to rumen flora or the animals.

These results apply to areas where growing stock graze cured and dry grass that contains less than 20 ppm Zn. Animals grazing some forbs may be able to meet their Zn requirement, because forbs often have more than 40 ppm Zn. Zn in galvanized pipe and water troughs dissolves into the drinking water, providing another source of Zn.

However, plastic water lines are extensively used, and in many areas, animals graze mature or dry grass with low Zn concentrations. Under these conditions, adequate Zn may not be available for growing stock.

Literature Cited

Apgar, J. and H. F. Travis. 1979. Effect of low zinc diet on the ewe during pregnancy and lactation. J. Anim. Sci. 48:1234.

Beeson, W. N., T. W. Perry and T. B. Zurcher. 1977. The effect of supplemental zinc on growth and on hair and blood serum levels of beef cattle. J. Anim. Sci. 45:160.

Blackmon, D. M., W. J. Miller and J. D. Morton. 1967. Zinc deficiency in ruminants. Vet. Med. 62:265.

Chapman, H. D. and P. F. Pratt. 1961. Methods of analysis for soils, plants, and waters. Div. Agr. Sci.. Univ. of California.

Egan, A. R. 1972. Reproductive responses to supplemental zinc and manganese in grazing Dorset Horn ewes. Australian J. Exp. Agr. Anim. Husb. 12:131.

Harvey, W. R. 1960. Least-squares analysis of data with unequal subclass numbers. USDA, ARS 20-8.

Healy, W. B. 1972. *In vitro* studies on the effects of soil in elements in ruminal duodenal and ileal liquors from sheep. New Zealand J. Agr. Res. 15:289.

Kincaid, R. L. 1979. Biological availability of zinc from inorganic sources with excess dietary calcium. J. Dairy Sci. 62:1081.

Legg, S. P. and L. Sears. 1960. Zinc sulphate treatment of parakeratosis in cattle. Nature 186:1061.

Mayland, H. F., A. R. Florence, R. C. Roseanau, V. A. Lazar and H. A. Turner. 1975. Soil ingestion by cattle on semiarid range as reflected by titanium analysis of feces. J. Range Manage. 28:448.

Miller, W. J. 1969. Absorption, tissue distribution, endogenous excretion, and homeostatic control of zinc in ruminants. Amer. J. Clin. Nutr. 22:1323.

Mills, C. F., A. C. Dalgarno, R. B. Williams and J. Quarterman. 1967. Zinc deficiency and the zinc requirements of calves and lambs. Brit. J. Nutr. 21:751.

Murray, R. B., H. F. Mayland and P. J. Van Soest. 1978. Growth and nutritional value to cattle of grasses on cheatgrass range in southern Idaho. USDA Forest Serv. Res. Paper INT-199, Intermt. Forest and Range Exp. Sta., Ogden, UT.

Papasteriadis, A. A. 1973. Study on the zinc deficiencies in ruminants under Greek conditions. Science Yearbook. Vet. Faculty 14:169, Aristotelian Univ. of Thessaloniki, Greece.

Perdomo, J. T., R. L. Shirley and C. F. Chicco. 1977. Availability of nutrient minerals in four tropical forages fed freshly chopped to sheep. J. Anim. Sci. 45:1114.

Perry, T. W., W. M. Beeson, W. H. Smith and M. T. Mohler. 1968. Values of zinc supplementation of natural rations for fattening beef cattle. J. Anim. Sci. 27:1674.

Pierson, R. E. 1966. Zinc deficiency in young lambs. J. Amer. Vet. Med. Assoc. 149:1279.

Schwarz, W. A. and M. Kirchgessner. 1975a. Experimental zinc deficiency in lactating dairy cows. Vet. Med. Rev. 1:19.

Schwarz, W. A. and M. Kirchgessner. 1975b. Zinc excretion in lactating cows receiving varying levels of zinc. Arch. Tierernahrung 25:597.

Somers, M. and E. J. Underwood. 1969. Studies of zinc nutrition in sheep. II. The influence of zinc deficiency in ram lambs upon the digestibility of the dry matter and the utilization of the nitrogen and sulfur of the diet. Australian J. Agr. Res. 20:899.

Spais, A. G. and A. A. Papasteriadis. 1973. Zinc deficiency in cattle under Greek conditions. *In* W. G. Hoekstra, J. R. Doe and J. Smith (Ed.) Trace Element Metabolism in Animals, No. 2. Proceedings of the Second International Symposium, Madison, WI, June 18-22, 1973. University Park Press, Baltimore, MD.

Stake, P. E., W. J. Miller and R. P. Gentry. 1973. Zinc metabolism and homeostasis in ruminants as affected by dietary energy intake and growth rate. Soc. Exp. Biol. Med. Proc. 142:494.

Stewart, B. A. and L. K. Porter, 1969. Nitrogen-sulfur relationships in wheat (*Triticum aestivum* L.), corn (*Zea mays*), and beans (*Phaseolus vulgaris*). Agron. J. 61:267.

Suttle, N. F. and A. C. Field. 1970. Effects of dietary calcium and phosphorus concentrations on the fecal excretion of copper, manganese and zinc in sheep. Pro. Nutr. Soc. 29:33A.

Whanger, P. D., S. H. Oh and J. T. Deagen. 1979. Zinc accumulation in tissue cytosolic proteins of sheep and cattle. J. Anim. Sci. 48(Suppl. 1):418.