



The effect of excess calcium with borderline and deficient phosphorus in the rations of steer calves
by James K Lewis

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree
of Master of Science in Animal Industry

Montana State University

© Copyright by James K Lewis (1950)

Abstract:

The results of two experiments involving 77 steer calves individually fed for 105 and 120 days, respectively, on rations containing adequate, borderline, or deficient phosphorus with normal or excess calcium are reported. Rations were supplemented with vitamins A and D, and with iodine, cobalt, copper, and manganese.

Feed consumed per 100 pounds body weight per day and average daily gains were reduced by borderline or deficient phosphorus intakes. Excess calcium added to a ration of borderline phosphorus content further reduced both feed consumption and rate of gain. However, when excess calcium was added to a deficient phosphorus ration, feed consumption was decreased, but rate of gain was not affected*. The correlation coefficient between feed consumed per 100 pounds body weight and rate of gain was -0.640 .

The phosphorus plasma levels were related in a general way to the phosphorus intake, but the calcium plasma level showed a characteristic fluctuation which was unaffected by treatments or by phosphorus plasma levels. The carotene plasma levels were inversely proportional to the phosphorus plasma levels and to the phosphorus intake and appeared to be directly proportional to the calcium intake. The symptoms of phosphorus deficiency in the order of their appearance were: impaired feed utilisation, reduction in rate of gain, poor feed consumption, depraved appetite, emaciation, rough hair coat, stiffness of the hind legs, enlargement of the knees and hocks, and alteration of body conformation. Depraved appetite was present in all lots and was partly attributed to the finely-divided state in which the ration was fed. Steers wintered on inadequate intakes of phosphorus with either normal or excess calcium made excellent gains on summer pasture and grain supplemented with phosphorus.

When phosphorus deficient steers were drenched with about 15 grams of phosphorus daily from monosodium phosphate there was marked improvement in feed consumption, feed efficiency, weight gains, vigor, and general appearance. A case of phosphate tetany in a steer is described which was induced by drenching with 0.76 grams per kilogram body weight of monosodium phosphate. A digestion trial with lambs is reported which shows that the lignin used as a filler in the experimental rations had no effect on their digestibility.

THE EFFECT OF EXCESS CALCIUM WITH BORDERLINE AND DEFICIENT
PHOSPHORUS IN THE RATIONS OF STEER CALVES

by

JAMES K. LEWIS

A THESIS

Submitted to the Graduate Faculty

in

partial fulfillment of the requirements

for the degree of

Master of Science in Animal Industry

at

Montana State College

Approved:

Fred S. Willson
Head, Major Department

William H. Burkitt
Chairman, Examining Committee

L. J. Nelson
Dean, Graduate Division

Bozeman, Montana
August, 1950

N378
L585e
Cap. 2

-2-

TABLE OF CONTENTS

ABSTRACT	7
INTRODUCTION	9
REVIEW OF THE LITERATURE	15
EXPERIMENT 1	
Methods and Procedure	20
Results and Discussion	25
Notes and Comments	25
Vitamin A Deficiency	27
Feed Consumption and Rate of Gain	29
Calcium and Phosphorus Plasma Levels	29
Feeder Grade and Condition Score	31
Salt Consumption	31
Photographic Studies	31
EXPERIMENT 2	
Methods and Procedure	40
Results and Discussion	46
Notes and Comments	46
Feed Consumption	48
Rate of Gain	57
Efficiency of Feed Utilization	60
Blood Chemistry	61
Calcium and Phosphorus	61
Carotene	61
Feeder Grade and Condition	65

96016

JAN 25 '51 Gift Graduate Committee

Salt Consumption	.69
Photographic Studies	.71
Effect of Phosphate Drenching	.72
Toxic Effect of Overdosage	.82
Effect on Performance	.84
Lignin Digestion Trial	.86
Performance of Steers on Pasture	.89
SUMMARY AND CONCLUSIONS	.92
LITERATURE CITED	.96

TABLES

Table I.	Recommended Nutrient Allowances for Normal Growth of Heifers and Steers	.10
Table II.	Calcium and Phosphorus Contents of Range Grass Near Livingston, Montana at Different Stages of Maturity.	.11
Table III.	Feed and Estimated Chemical Composition of Rations Fed in Experiment 1	.22
Table IV.	Calcium and Phosphorus Content of Concentrate Mixtures and Hay Fed in Experiment 1	.26
Table V.	Vitamin A and Carotene Content of the Blood Plasma of the Steers on Experiment 1	.27
Table VI.	Performance of Steers on Experiment 1 as Measured Over Entire Period of 105 Days	.28
Table VII.	Effect of the Experimental Rations on the Feeder Grade and Condition Score of the Steers in Experiment 1.	.30
Table VIII.	Effect of the Experimental Rations on the Salt Consumption of the Steers on Experiment 1	.32
Table IX.	Feed and Chemical Composition of Rations as Fed in Experiment 2	.41
Table X.	Performance of Steers in Experiment 2 Measured Over the First 120 Days	.49

Table	XI.	Performance of Steers on Experiment 2 in Lot 1 as Measured by Weigh Periods	50
Table	XII.	Performance of Steers on Experiment 2 in Lot 2 as Measured by Weigh Periods	51
Table	XIII.	Performance of Steers on Experiment 2 in Lot 3 as Measured by Weigh Periods	52
Table	XIV.	Performance of Steers on Experiment 2 in Lot 4 as Measured by Weigh Periods	53
Table	XV.	Performance of Steers on Experiment 2 in Lot 5 as Measured by Weigh Periods	54
Table	XVI.	Effect of the Experimental Rations on the Carotene Plasma Levels of the Steers on Experiment 2 . . .	64
Table	XVII.	Effect of Experimental Rations on the Feeder Grade and Condition of the Steers on Experiment 2 . . .	66
Table	XVIII.	Effect of the Experimental Rations on the Salt Consumption of the Steers on Experiment 2. (120 Days).	70
Table	XIX.	Effect of Phosphate Drenching on the Performance of the Steers on Experiment 2 in Lots 3 and 5 during the Fifth Weigh Period	85
Table	XX.	Feed Mixtures Fed in the Lignin Digestion Trial With Lambs	87
Table	XXI.	The Effect of Lignin on the Apparent Digestibility of Ration 1 by Lambs	88
Table	XXII.	Effect of the Experimental Rations Fed During the Winter on Weight Gains of the Steers on Summer Pasture	90

FIGURES

Figure 1.	The Known Phosphorus Deficient Areas in Montana	8
Figure 2.	Seasonal Variations in the Phosphorus Content of Principal Range Grasses of Eastern Montana.	12
Figure 3.	Seasonal Variations in the Calcium Content of Principal Range Grasses of Eastern Montana	13

Figure 4.	An Exercise Lot Used in These Studies	.21
Figure 5.	Individual Feeding Stanchions Used in These Studies . .	.21
Figure 6.	The Measuring Chute Used in the Photographic Studies.	.34
Figure 7.	The Photographic Chute in Operation. The Steel Rods Are Spaced 6 Inches Apart	.34
Figure 8.	Representative Steers From Lot 1 on Experiment 1 Before and After Treatment	.35
Figure 9.	Representative Steers From Lot 2 on Experiment 1 Before and After Treatment	.36
Figure 10.	Representative Steers From Lot 3 on Experiment 1 Before and After Treatment	.37
Figure 11.	Representative Steers From Lot 4 on Experiment 1 Before and After Treatment	.38
Figure 12.	Representative Steers From Lot 5 on Experiment 1 Before and After Treatment	.39
Figure 13.	Wood-chewing by a Phosphorus Deficient Steer	.45
Figure 14.	The Barn Wall Partially Eaten by Phosphorus Deficient Steers	.47
Figure 15.	Well-gnawed Corral Poles	.47
Figure 16.	Feed Consumption and Weight Gains of the Steers on Experiment 2 by Weigh Periods	.56
Figure 17.	Phosphorus Intake and Weight Gains of the Steers on Experiment 2 by Weigh Periods	.59
Figure 18.	Phosphorus Intake and Phosphorus Plasma Levels of the Steers on Experiment 2 by Weigh Periods	.62
Figure 19.	Calcium and Phosphorus Plasma Levels of the Steers on Experiment 2 by Weigh Periods	.63
Figure 20.	Steer 8 Fed Ration 5 Showing Poor Body Conformation Produced by Low Phosphorus and Excess Calcium in the Ration	.68
Figure 21.	Steer 8 Fed Ration 5 Showing a Very Typical Stance of a Phosphorus Deficient Steer.	.68

Figure 22.	Representative Steers From Lot 1 on Experiment 2 Before and After Treatment	.73
Figure 23.	Representative Steers From Lot 2 on Experiment 2 Before and After Treatment	.74
Figure 24.	Representative Steers From Lot 3 on Experiment 2 Before and After Treatment	.75
Figure 25.	Representative Steers From Lot 4 on Experiment 2 Before and After Treatment	.76
Figure 26.	Representative Steers From Lot 5 on Experiment 2 Before and After Treatment.	.77
Figure 27.	The Steers Fed Ration 1 at the End of Experiment 2 .	.78
Figure 28.	The Steers Fed Ration 2 at the End of Experiment 2 .	.78
Figure 29.	The Undrenched Steers Fed Ration 3 at the End of Experiment 2	.79
Figure 30.	The Drenched Steers Fed Ration 3 at the End of Experiment 2	.79
Figure 31.	The Steers Fed Ration 4 at the End of Experiment 2 .	.80
Figure 32.	The Undrenched Steers Fed Ration 5 at the End of Experiment 2	.81
Figure 33.	The Drenched Steers Fed Ration 5 at the End of Experiment 2	.81

ABSTRACT

The results of two experiments involving 77 steer calves individually fed for 105 and 120 days, respectively, on rations containing adequate, borderline, or deficient phosphorus with normal or excess calcium are reported. Rations were supplemented with vitamins A and D, and with iodine, cobalt, copper, and manganese.

Feed consumed per 100 pounds body weight per day and average daily gains were reduced by borderline or deficient phosphorus intakes. Excess calcium added to a ration of borderline phosphorus content further reduced both feed consumption and rate of gain. However, when excess calcium was added to a deficient phosphorus ration, feed consumption was decreased, but rate of gain was not affected. The correlation coefficient between feed consumed per 100 pounds body weight and rate of gain was $+0.640$. The phosphorus plasma levels were related in a general way to the phosphorus intake, but the calcium plasma level showed a characteristic fluctuation which was unaffected by treatments or by phosphorus plasma levels. The carotene plasma levels were inversely proportional to the phosphorus plasma levels and to the phosphorus intake and appeared to be directly proportional to the calcium intake. The symptoms of phosphorus deficiency in the order of their appearance were: impaired feed utilization, reduction in rate of gain, poor feed consumption, depraved appetite, emaciation, rough hair coat, stiffness of the hind legs, enlargement of the knees and hocks, and alteration of body conformation. Depraved appetite was present in all lots and was partly attributed to the finely-divided state in which the ration was fed. Steers wintered on inadequate intakes of phosphorus with either normal or excess calcium made excellent gains on summer pasture and grain supplemented with phosphorus.

When phosphorus deficient steers were drenched with about 15 grams of phosphorus daily from monosodium phosphate there was marked improvement in feed consumption, feed efficiency, weight gains, vigor, and general appearance. A case of phosphate tetany in a steer is described which was induced by drenching with 0.76 grams per kilogram body weight of monosodium phosphate. A digestion trial with lambs is reported which shows that the lignin used as a filler in the experimental rations had no effect on their digestibility.

Continental Divide ==

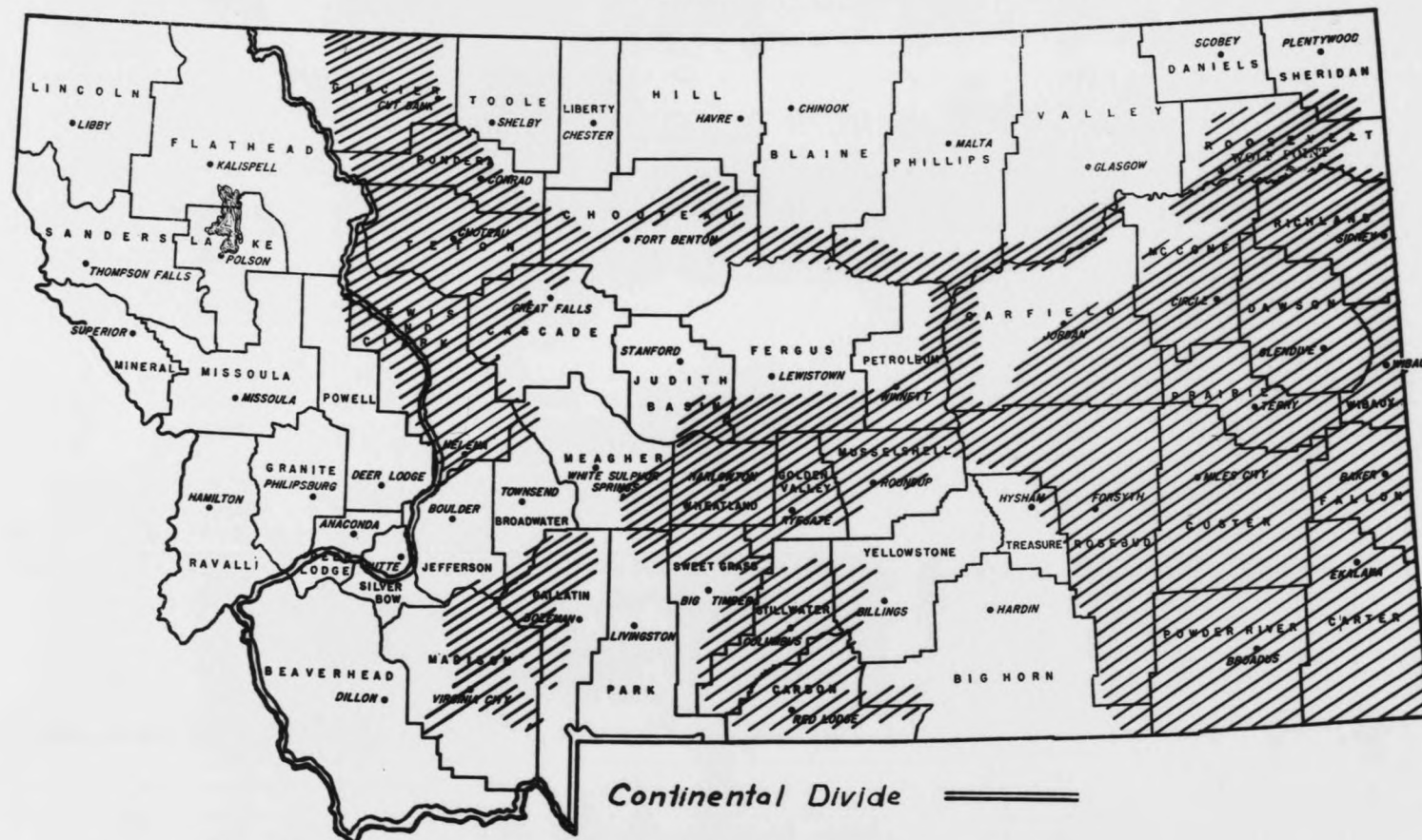


Figure 1. The Known Phosphorus Deficient Areas in Montana
(after Welch, 1950)

THE EFFECT OF EXCESS CALCIUM WITH BORDERLINE AND DEFICIENT PHOSPHORUS IN THE RATIONS OF STEER CALVES

Introduction

Most of Montana's rangeland lies in an area of calcareous, alkaline soils with low available phosphorus, and low precipitation. Phosphorus deficiency in cattle has been recognized on these ranges for many years. The Veterinary Research Department at Montana State College advised feeding bone meal to prevent bone chewing and other symptoms of phosphorus deficiency as long ago as 1910. (Welch, 1924) Nevertheless, phosphorus deficiency remains as one of the chief problems in many areas. The known phosphorus deficient areas of Montana as indicated by livestock reports and a few forage analyses are shown in figure 1. This map does not positively and definitely delineate areas of phosphorus deficiency, but rather is a composite of reports of deficiency symptoms in livestock received by the Veterinary Research Laboratory over a period of some 40 years.

Phosphorus deficiency in the forage may be due to one or more of the following:

- 1) Lack of available phosphorus in the soil. (Burke and Morris, 1941; Bard, 1949)
- 2) Drouth, which reduces the phosphorus content of the forage and decreases the total volume of forage produced, limits the phosphorus intake of the grazing animal by reducing both the percentage of the mineral in the forage and the total pounds of forage consumed. The latter consideration, however, is not valid if proper stocking is maintained. (Clarke and Tisdale, 1945)

TABLE I. RECOMMENDED NUTRIENT ALLOWANCES FOR NORMAL GROWTH OF HEIFERS AND STEERS. ^{1/}

Body wt. lbs.	Expected daily gain lbs.	Daily feed per hundred lbs. of body wt. lbs.	Digestible nutrients in ration %	Digestible protein in ration %
400	1.6	3.0	58	7.5
600	1.4	2.7	53	5.7
800	1.2	2.4	50	4.7

Table I. Continued:

Body wt. lbs.	Calcium in ration %	Calcium daily per animal grams	Phosphorus in ration %	Phosphorus daily per animal grams
400	0.37	20	0.28	15
600	0.25	18	0.21	15
800	0.19	16	0.17	15

^{1/} Adapted from National Research Council, 1945.

- 3) Seasonal variations in the phosphorus content of the plant.
(Savage and Heller, 1947; Clarke and Tisdale, 1945; Watkins, 1943; Sarvis, 1941; Gordon and Sampson, 1939; Stanley and Hodgson, 1938; Hart, Guilbert, and Goss, 1932)

Figure 2 shows the percentage of phosphorus contained in the three principal forage plants sampled from August through December 1948 and from March through December 1949 at the U. S. Range Livestock Experiment Station at Miles City by the Animal Industry and Range Management Department of Montana State College. (Payne, 1950) The differences in the phosphorus percentages for these three grasses in 1948, a year of above average moisture conditions, and in 1949, a drouth year, are quite striking. The forage at no time in 1949 was adequate to meet the National Research Council recommendations for calves weighing less than 800 pounds as shown in Table I. Figure 2 also shows the seasonal variations in phosphorus content of the forage from a high in early May to a winter low. Figure 3 shows the seasonal trend in the calcium content of the principal range grasses at Miles City from July through December 1949. A similar seasonal change in calcium and phosphorus is shown by analyses of range forage from north of Livingston, Montana in Table II. (Lewis and Burkitt, 1949)

TABLE II. CALCIUM AND PHOSPHORUS CONTENTS OF RANGE GRASS NEAR LIVINGSTON, MONTANA AT DIFFERENT STAGES OF MATURITY. (Air-dry basis)

Season sampled	Calcium %	Phosphorus %	Calcium to one phosphorus
July 1948	0.51	0.14	3.64
September 1948	0.44	0.09	4.90
February 1949	0.36	0.05	7.20

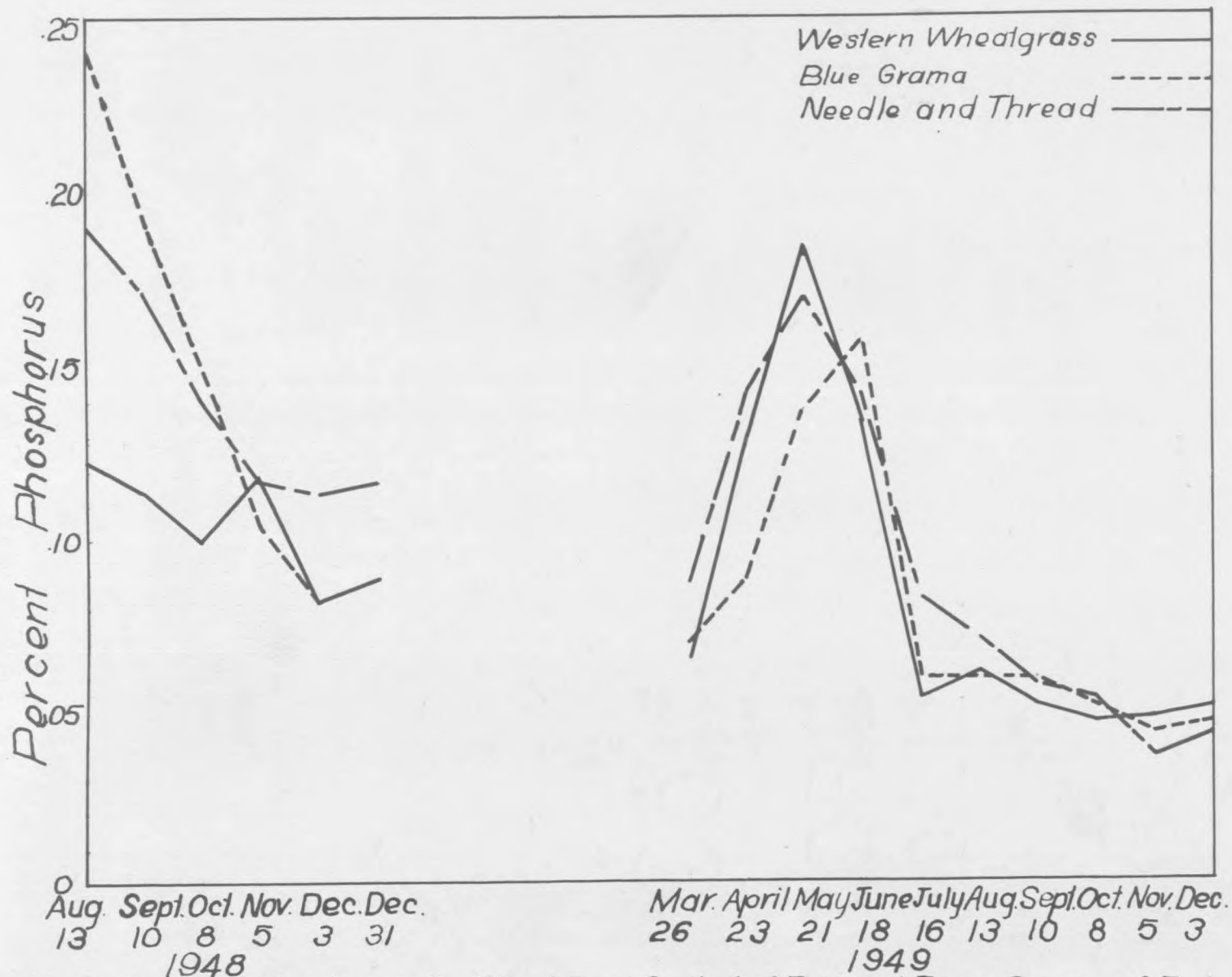


Fig. 2. Seasonal Variations in the Phosphorus Content of Principal Range Grasses of Eastern Montana

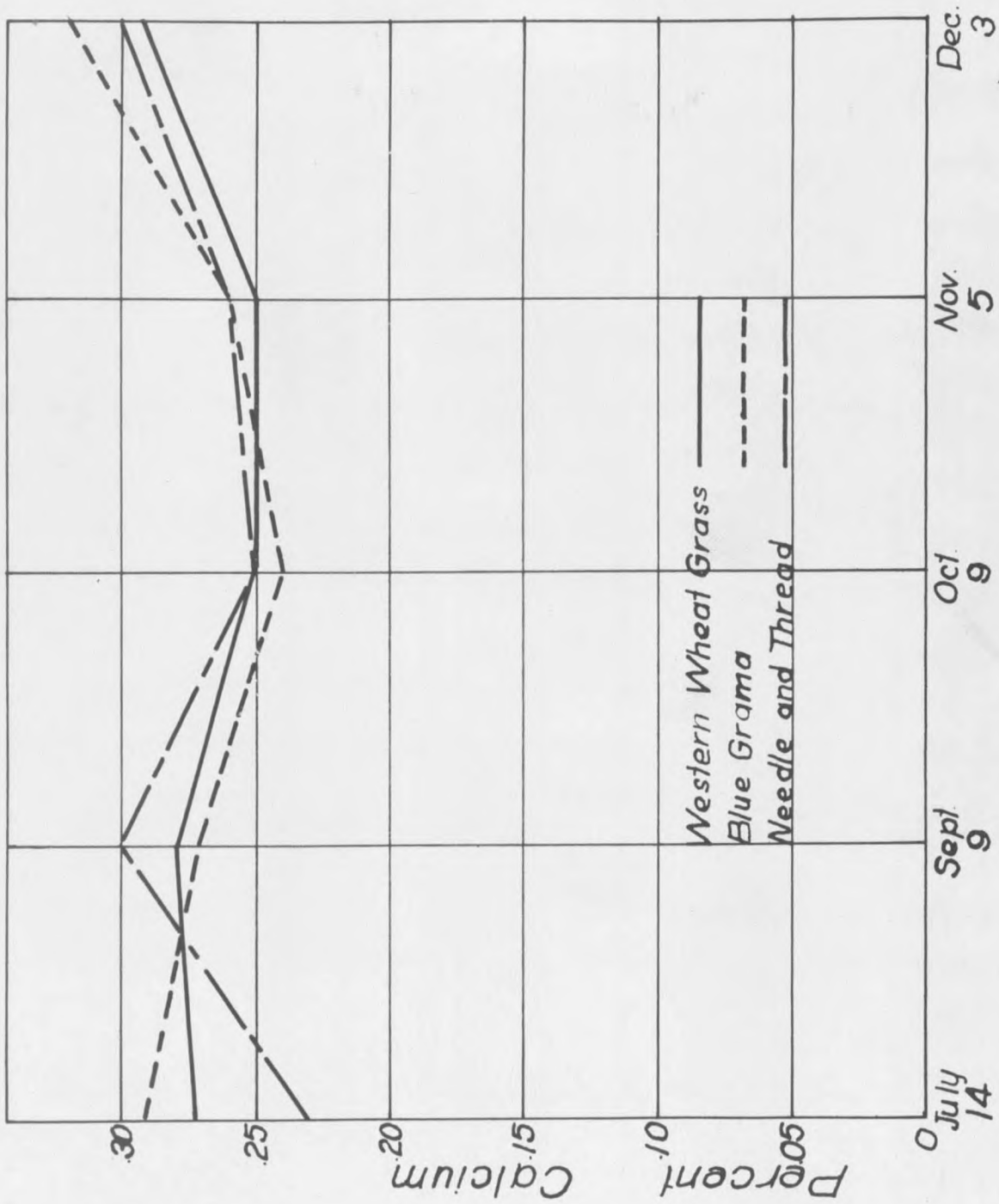


Fig. 3. Seasonal Variation in the Calcium Content of Principal Range Grasses of Eastern Montana

Figures 2 and 3 also show that as the season advances, the calcium to phosphorus ratio steadily widens from less than 2:1 at the peak of the growing season to more than 7:1 during the winter.

Thus, the situation on many of our Montana ranges is one of borderline or deficient phosphorus in the forage with sufficient or excess calcium. Nevertheless, most of the mineral supplements fed to correct phosphorus deficiency in this area contain inadequate amounts of phosphorus and appreciable quantities of calcium. The latest Montana Commercial Feeds Report (Gaines, 1948) listed 16 mineral feeds sold in the state. Only one of these contained as much as ten percent phosphorus and some contained appreciable quantities of calcium. Eckles and Gullickson (1933) confronted by a similar situation wrote--- "When cattle are suffering from a lack of phosphorus there is no object in feeding a mineral mixture containing large quantities of lime and common salt. In fact, results from experimental work indicate that including lime in the form of limestone or marl under these conditions actually makes the trouble worse."

Therefore, this experiment was designed to study the effect on the performance of steer calves of feeding borderline or deficient phosphorus rations containing adequate or excessive calcium.

REVIEW OF LITERATURE

The literature pertaining to calcium and to phosphorus compounds in animal nutrition is voluminous. Forbes and Keith (1914) published a 748 page review of the literature of the phosphorus compounds in animal metabolism. Theiler and Green (1932) reviewed the literature concerning phosphorus deficiency in ruminants. Fairbanks (1939) reviewed the literature concerning the effect of the calcium-phosphorus ratio on the utilization of calcium and phosphorus.

Tereg and Arnold in 1883 (Forbes and Keith, 1914) working with dogs suggested that "... a lack of proportion between these elements (calcium and phosphorus) restricts the usefulness of both." Du Toit et al. (1933) fed 2 groups of four calves each from 2 months to 11 months of age on adequate phosphorus rations which varied only in the amount of calcium carbonate added. The calcium to phosphorus ratios of the 2 groups were held constant throughout the period at ratios of 5.5:1 and 1.2:1 respectively. They found no difference in feed consumption, weight gains, or appearance of these two groups.

Eckles and Gullickson (1933) fed 2 cows weighing approximately 800 pounds for 9 months on similar rations containing approximately 9.0-9.5 grams of phosphorus per day. The cows received 35 and 180 grams of calcium per day respectively. The cow receiving a normal calcium intake showed a steady decline in the plasma phosphorus level to 2.62 mg. per 100 ml., but did not develop pica or exhibit phosphorus deficiency symptoms. However, the animal receiving an excess of calcium became unthrifty and rough in appearance, showed pica almost constantly, and the plasma phosphorus level

dropped to 1.26 mg. per 100 ml.

Theiler and Green (1932) expressed the opinion that an excess of calcium might hinder the absorption of phosphorus from the intestine, but that the ratio of calcium to phosphorus in the body was of less importance.

Shohl (1936) working with rats fed on vitamin D free rations found that adequate amounts of both calcium and phosphorus were required to prevent rickets regardless of the ratio between them. However, at high levels of either nutrient, the requirement of the other was increased.

Cox and Imboden (1936) studying the effects of calcium and phosphorus on reproduction in the rat concluded that if adequate but not excessive amounts of both nutrients were supplied, satisfactory performance was attained irrespective of the ratio. However, when the phosphorus intake was held constant at an adequate level (0.245 grams per day) and the daily calcium intake increased from 0.490 to 1.225 to 2.45 grams per day, the "Success Rating" ^{1/} decreased from 90.4 to 13.2 to 0.5 and the feed consumption declined from 65.1 to 62.7 to 40.5 calories per day respectively.

Fairbanks (1939) stated that the importance of the calcium to phosphorus ratio on the utilization of these minerals had been overrated, and that there were 5 equally important factors affecting their utilization:

- (1) The availability of calcium and phosphorus in the ration.
- (2) The concentration of each in the ration.
- (3) The presence of vitamin D or ultra-violet irradiation.
- (4) The rate of food consumption and thus the rate of growth.

^{1/} The Success Rating was based on the weight of the young at 28 days, the ash content of the young, and the net change in the body weight of the mother.

(5) The calcium to phosphorus ratio.

Theiler, DuToit, and Malan (1937) fed twelve 15 month old Friesland heifers on similar rations with the following amounts of calcium and phosphorus for 20 months:

1. Adequate calcium (19.22 grams daily) and adequate phosphorus (10.47 grams daily)
2. Adequate calcium (17.06 grams daily) and low phosphorus (4.32 grams daily)
3. Excess calcium (43.31 grams daily) and low phosphorus (3.01 grams daily)
4. Low calcium (4.22 grams daily) and low phosphorus (4.62 grams daily)
5. Excess calcium (43.95 grams daily) and adequate phosphorus (10.47 grams daily)
6. Low calcium (3.93 grams daily) and adequate phosphorus (10.47 grams daily)

The adequate phosphorus levels used by these workers were actually borderline levels of phosphorus intake according to the National Research Council (1945). The animals fed ration 2 (adequate calcium-low phosphorus) were difficult to keep on feed and ceased to gain in weight after 3 to 4 months on experiment. The plasma phosphorus was very low, the bones were weak, and calcium and phosphorus retention was very poor as compared with lot 1 (adequate calcium-adequate phosphorus). The heifers in lot 3 (excessive calcium-low phosphorus) consumed slightly less feed, made poorer gains, had weaker bone structure, but showed the same blood picture and had

better calcium and phosphorus retention than those in lot 2 (adequate calcium-low phosphorus). The lot 5 heifers, fed excess calcium with adequate phosphorus, showed no depression in performance as compared with lot 1 (adequate calcium-adequate phosphorus) except for reduced retention of both minerals. Both lots 4 (low calcium-low phosphorus) and 6 (low calcium-adequate phosphorus) compared favorably with lot 1 except for lowered breaking strength of the bone and poor retention of both minerals. The plasma phosphorus of lot 4, however, was still lower than in lot 2. The authors concluded in part that the poor weight gains were due primarily to poor feed consumption in the deficient lots and that excess calcium was without effect on performance as long as the phosphorus content of the ration was adequate.

Beeson, Bolin, Hickman, and Johnson (1941), in studying the phosphorus requirements for growing and fattening steers, maintained a constant calcium intake with varying phosphorus intake, so that the calcium to phosphorus ratio varied from 2.2:1 to 6.8:1. These workers believed that since the vitamin D was adequate and since practical farm rations often contained wide ratios of calcium to phosphorus, it was better not to adjust the calcium to phosphorus ratio for the purpose of establishing the phosphorus requirements for fattening steers.

Greenberg, (1947) reviewing the literature concerning calcium and phosphorus metabolism concluded that, although the absorption of calcium and phosphate appeared to be largely independent processes, excessive amounts of calcium did offer considerable hinderance to phosphorus absorption.

Morrison (1948) stated that "Apparently, little attention need be given to the ratio between the amounts of calcium and phosphorus in feeding cattle or sheep, if an adequate amount of each mineral is supplied."

Thus there appears to be some confusion in the literature regarding the effect of an excess of calcium on the utilization of phosphorus by calves, particularly under conditions of borderline phosphorus intake, such as frequently prevail on Montana ranges.

EXPERIMENT 1

METHODS AND PROCEDURE

Forty steer calves were obtained from the Climbing Arrow Ranch in the Fall of 1948 and were wintered on timothy hay and salt. Their winter gain averaged 0.75 pound per head per day. On April 23, 1949 the steers were allotted into 5 lots of 8 steers each 2/ on the basis of weight, plasma phosphorus feeder grade 3/, condition, and plasma calcium. The steers were identified by eartags and by a paint brand. The various lots were housed in separate but adjacent pens with free access to water and salt. Figure 4 shows the outdoor pens and figure 5 shows the individual feeding stalls which were used in both Experiment 1 and Experiment 2. The steers were weighed and placed on the experimental rations shown in Table III 4/ at the evening feeding on May 3. These rations were identical except for different amounts of calcium, phosphorus and lignin. The lignin was used as a filler and was assumed to be inert.

Ration 1 was considered to contain adequate but not excessive amounts of calcium and phosphorus. (National Research Council, 1945) Ration 2 was considered to be borderline in phosphorus content (Beeson et al., 1941) and contained the same amount of calcium as did ration 1. Ration 4 was the same as ration 2 except that an excess of gypsum had been added. Ration 3 was deficient in phosphorus (Beeson et al., 1941) and contained the same amount of calcium as ration 1. Ration 5 was the same as ration 3 except

2/ Steer 5 in lot 3 was removed from the experiment on May 5 because of extreme nervousness.

3/ Steers were graded for feeder grade and condition by R. L. Davis, W. H. Burkitt, and J. K. Lewis.

4/ Experimental rations were mixed by Misco Mills, Bozeman, Montana.



Figure 4 An Exercise Lot Used in These Studies



Figure 5 Individual Feeding Slanchions Used in These Studies

TABLE III. FEED AND ESTIMATED CHEMICAL COMPOSITION OF RATIONS FED IN
EXPERIMENT 1.

RATION NO.	I	II	III	IV	V
	%	%	%	%	%
Timothy	20.0	20.0	20.0	20.0	20.0
Dried Molasses Beet Pulp	33.0	33.0	33.0	33.0	33.0
Oat Straw	9.8	9.8	9.8	9.8	9.8
Corn	12.0	12.0	12.0	12.0	12.0
Cane Molasses	7.0	7.0	7.0	7.0	7.0
Blood Meal	5.2	5.2	5.2	5.2	5.2
"Two-sixty-two" 1/	1.0	1.0	1.0	1.0	1.0
Dextrose 2/	6.0	6.0	6.0	6.0	6.0
Lignin 3/	4.7	5.0	5.2	—	0.2
Iodized Salt	0.8	0.8	0.8	0.8	0.8
Gypsum	—	—	—	5.0	5.0
Mono-sodium phosphate	0.5	0.2	—	0.2	—
TOTAL	100.0	100.0	100.0	100.0	100.0
Crude protein	13.49	13.49	13.49	13.49	13.49
T.D.N. (estimated)	59.9	59.9	59.9	59.9	59.9
Calcium	0.347	0.347	0.347	1.402	1.402
Phosphorus	0.243	0.176	0.131	0.176	0.131
Parts calcium to one part phosphorus	1.43	1.97	2.65	7.97	10.70

1/ Urea product of E. I. DuPont de Nemours and Co., Inc.

2/ By product from production of wood molasses, supplied gratis by Forest Products Laboratory, U. S. Forest Service, Madison, Wisconsin.

3/ Cerelese, Corn Products Sales Company, St. Paul, Minnesota.

4/ $\text{CoSO}_4 \cdot 7\text{H}_2\text{O}$ was added at the rate of 2 grams per 1000 lbs. of concentrate mixture to all rations.

5/ 4 cc. of vitamin A-D feeding oil, guaranteed potency 3000 I. U. of A and 400 I. U. of D per gram was fed on top of the concentrate mixture every other day.

that an excess of gypsum had been added. Ration 1 was a control ration. The effect of adding an excess of gypsum to the ration of these calves was studied by comparing lots 2 and 4 and lots 3 and 5. The rations were supplemented with 2 cc. per head per day of A-D feeding oil having a guaranteed potency of 3000 International Units of vitamin A and 400 International Units of vitamin D per gram, but which by analyses contained from 410-570 International Units of vitamin A per gram.

The steers were individually fed according to appetite for 105 days and the weighback recorded. At 28 day intervals the steers were weighed and 40 cc. of blood drawn from the jugular vein for calcium and phosphorus determinations. 5/ Inorganic phosphorus was determined according to the method described by Fiske and Subbarow (1925). Readily ionizable calcium was isolated as calcium oxalate by the method of Koch (1937) and determined colorimetrically by the method of De Loureiro and Janz (1944). Carotene and vitamin A were determined by the analytical procedure of Boyer, Phillips, and Smith (1944). All blood analyses were made on the plasma.

Individual photographs were made in a measuring chute at the beginning and at the end of the trial. The steers were graded for feeder grade and condition at the end of the trial. 6/ All lots were bedded with wood shavings. Samples of the hay and the concentrate mixtures were taken as they were fed and analyzed at the end of the trial for calcium, phosphorus and protein. The weighback from each steer was analyzed for moisture,

5/ Blood analyses were made by Dr. Karl Swingle of the Veterinary Research Laboratory.

6/ Steers were graded at the end of the trial by E. P. Orcutt, Extension Animal Husbandman.

protein, calcium, and phosphorus. Z/ All feed analyses were made according to standard Association of Official Agricultural Chemists procedures (1945).

Z/ Feed analyses were made by Dr. Leon Johnson of the Chemistry Research Department.

CORRASABLE

BOND

USE

STRAKSHIRE

RESULTS AND DISCUSSION

Notes and Comments

The chemical compositions of the rations fed in this experiment were extremely variable. Table IV shows that ration 1, which was planned as an adequate calcium, adequate phosphorus ration was actually a phosphorus deficient ration for the last 29 days of the trial. The supposedly normal calcium, borderline phosphorus ration fed to lot 2 was adequate in phosphorus until the second batch of hay was fed on July 12. The deficient phosphorus ration fed to lot 3 was deficient for the first 39 days, adequate for the following 31 days, borderline for the next 19 days and deficient for the last 16 days of the experiment. Ration 4, designed as a high calcium-borderline phosphorus ration, was adequate in phosphorus content until July 12 when it became borderline. Thus the performance of the steers in lot 4 may be compared with that of those in lot 2 to study the effect of the excess gypsum added to ration 4. Ration 5, designed as a high calcium-low phosphorus ration to be compared with ration 3, actually contained normal calcium and low phosphorus for the first 33 days of the trial. Thereafter it did contain excess calcium and deficient phosphorus. The ability of the steers to store phosphorus during periods of adequacy made it difficult to evaluate the performance of the steers fed rations of variable phosphorus content.

All steers in all lots exhibited pica after about the first 17 days on the experimental rations. Theiler et al. (1937) attributed pica in their experimental animals fed adequate phosphorus to a lack of bulk in the ration. Cole (Eveleth, et al., 1949) noted the same phenomenon in sheep

TABLE IV. CALCIUM AND PHOSPHORUS CONTENT OF CONCENTRATE MIXTURES AND HAY FED IN EXPERIMENT 1.

RATION	Dates fed	Number of days fed	Chemical Composition	
			Calcium	Phosphorus
			%	%
Ration 1 - First mix	May 3 - June 9	37	0.42	0.32
Second mix	June 9 - July 18	39	0.62	0.31
Third mix	July 19 - Aug. 16	29	0.53	0.14

Ration 2 - First mix	May 3 - June 2	31	0.45	0.20
Second mix	June 2 - Aug. 16	74	0.61	0.19

Ration 3 - First mix	May 3 - June 12	41	0.38	0.12
Second mix	June 12 - Aug. 1	48	0.61	0.19
Third mix	Aug. 1 - Aug. 16	16	0.55	0.15

Ration 4 - First mix	May 3 - June 11	40	1.55	0.17
Second mix	June 11 - Aug. 4	53	1.77	0.19
Third mix	Aug. 5 - Aug. 16	12	1.66	0.20

Ration 5 - First mix	May 3 - June 4	33	0.58	0.13
Second mix	June 4 - Aug. 11	67	1.53	0.14
Third mix	Aug. 11 - Aug. 16	5	1.77	0.13

Timothy hay	May 3 - July 12	70	0.53	0.20
Timothy hay	July 12 - Aug. 16	35	0.40	0.11

fed finely ground rations. It is probable that the pica observed in these animals was due at least in part to the finely divided state in which the rations were fed.

Vitamin A Deficiency

Although A-D Feeding Oil was fed every other day, mild symptoms indicating vitamin A deficiency were noted in some steers by July 23. A maze test at dusk showed one steer each from lots 1, 3, and 4 to be night blind. The amount of A-D Feeding Oil fed was doubled. An analysis of the oil showed a vitamin A content of only 524 I. U. per gram instead of the guaranteed potency of 3000 I. U. per gram. Blood samples for vitamin A and carotene determinations were taken at random from every other animal in each lot on July 28 and on August 16. The results recorded in Table V show that four of the five lots were near or below the borderline level of 16 mcg. per 100 ml. reported by Davis and Madsen (1941).

TABLE V. VITAMIN A AND CAROTENE CONTENT OF THE BLOOD PLASMA OF THE STEERS IN EXPERIMENT 1.

Lots	1	2	3	4	5
	mcg. %	mcg. %	mcg. %	mcg. %	mcg. %
Plasma vitamin A, July 28	18.7	16.3	13.0	14.7	13.5
Plasma vitamin A, Aug. 16	22.0	25.3	18.2	17.5	17.8
Carotene, July 28	53.3	58.3	50.0	52.5	53.8
Carotene, Aug. 16	30.0	46.7	28.8	31.2	32.5

The differences in lot means appear to be due chiefly to differences in the intake of timothy hay.

A comparison of lots 2 and 4, Table VI shows that the excess gypsum added to ration 4 reduced feed consumption, and consequently the phosphorus

TABLE VI. PERFORMANCE OF STEERS ON EXPERIMENT 1 AS MEASURED OVER ENTIRE PERIOD OF 105 DAYS (May 3-August 16, 1949).

ITEMS MEASURED	LOT				
	I	II	III	IV	V
Number of steers	8	8	7	8	8
Phosphorus in the ration, %	0.23	0.19	0.17	0.18	0.15
Calcium in the ration, %	0.53	0.56	0.52	1.37	1.05
Parts calcium to one part phosphorus	2.25	3.00	3.16	7.49	7.07
Phosphorus intake-grams/100 lbs. body weight/day	2.51	2.12	1.63	1.66	1.26
Calcium intake-grams/100 lbs. body weight/day	5.64	6.07	5.13	12.46	8.90
Initial weight, lbs.	509	429	507	492	504
Feed consumed-lbs./100 lbs. body weight/day	2.50	2.38	2.16	2.00	2.22
Average daily gain, lbs.	1.77	1.96	1.33	0.94	0.80
Feed consumed-lbs./100 lbs. gain	796	723	934	1163	1272
Terminal calcium plasma level mg. %	10.1	11.6	11.8	10.8	10.6
Terminal phosphorus plasma level mg. %	5.8	4.3	1.7	5.7	3.4

intake, reduced the average daily gain, and decreased the efficiency of feed utilization without altering the blood picture.

Feed Consumption and Rate of Gain

Lack of appetite and poor feed consumption were the most outstanding symptoms of phosphorus deficiency. The general appearance of the deficient animals indicated starvations. The correlation coefficient between feed consumption and rate of gain was 0.909. Nevertheless, when all the lots were adjusted to the same feed consumption by analysis of covariance (Snedecor, 1946), the differences in the lot means for rate of gain were still significant at the 1 percent level. Therefore, reduced feed consumption was not the only primary effect of the lot treatments.

Calcium and Phosphorus Plasma Levels

The terminal blood phosphorus levels after storage has been depleted primarily reflect the current phosphorus intake and bear little relation to the previous phosphorus nutrition of the animal. Table IV shows that the steers in lot 3 had been on deficient, adequate, borderline, and finally for the last 15 days of the experiment, on a deficient level of phosphorus intake, yet the terminal phosphorus plasma level was only 1.7 mg. per 100 ml., the lowest recorded for any lot during the entire period. Lot 4, however, with approximately the same phosphorus intake per 100 pounds of body weight over the entire period, but which had been on a borderline phosphorus intake for several weeks, had a terminal phosphorus plasma level of 5.7 mg. per 100 ml.

The calcium plasma level appeared to be independent of the calcium intake as has been noted by previous investigators. (Mitchel, 1947;

TABLE VII. EFFECT OF THE EXPERIMENTAL RATIONS ON THE FEEDER GRADE AND CONDITION SCORE OF THE STEERS ON EXPERIMENT 1.

LOT	I	II	III	IV	V
Feeder Grade, April 4, 1949 <u>1/</u>	8.4	8.9	8.0	8.1	8.2
Feeder Grade, Aug. 20, 1949 <u>2/</u>	9.9	9.5	10.0	10.5	10.0
Change in Feeder Grade	1.5	0.6	2.0	2.4	1.8
Condition Score, April 4, 1949 <u>1/</u>	4.8	5.0	4.3	4.6	4.8
Condition Score, Aug. 20, 1949	4.8	3.3	4.2	7.7	7.8
Change in Condition Score	0	-1.7	-0.1	3.1	3.0

1/ Steers were graded by R. L. Davis, W. H. Burkitt, and J. K. Lewis on the basis of eighteen feeder grades:

Fancy - 1, 2, 3.

Choice - 4, 5, 6.

Good - 7, 8, 9.

Medium - 10, 11, 12.

Consumer - 13, 14, 15.

Inferior - 16, 17, 18.

and nine condition classes:

Good - 1, 2, 3.

Fair - 4, 5, 6.

Poor - 7, 8, 9.

2/ Steers were graded for feeder grade and condition by E. P. Orcutt, Extension Animal Husbandmen.

Theiler, et al., 1937; Theiler and Green, 1932; DuToit, et al., 1931)

Feeder Grade and Condition Score

The steers were rated for feeder grade and condition score by two different judges. The judge who rated the steers at the end of the trial did not help with the rating at the beginning of the trial. Table VII indicates that all lots were poorer in feeder grade at the close of the experiment with lots 3 and 4 showing the greatest decline. However, this decrease is only from average good to high medium. There was no appreciable change in the condition score of lots 1, 2, and 3, but lots 4 and 5, fed additional calcium, showed a decline in condition of one full class-- from fair to poor.

Salt Consumption

The salt consumption of the various lots is given in Table VIII. However, the chemical composition of the rations fed to the various lots was so extremely variable that the relationship of salt consumption to experimental treatment is obscure.

Photographic Studies

Individual photographs of each steer were made shortly after the beginning of the trial on June 23 and again near the end of the trial on August 17. The photographs were made in the measuring chute shown in figure 6, which is similar to that used by Guilbert et al., (1944). The lattice was made of one-fourth inch steel rods, spot-welded at the intersections, and set in an angle-iron frame. The steel rods are six inches apart measured from center to center. Figure 7 shows the chute in operation.

TABLE VIII. EFFECT OF THE EXPERIMENTAL RATIONS ON THE SALT CONSUMPTION
OF THE STEERS ON EXPERIMENT 1.

LOTS	I	II	III	IV	V
Salt consumed ad lib, oz./head/day	2.18	2.92	3.73	3.36	2.98
Salt consumed in ration, oz./head/day ^{1/}	2.25	2.27	1.99	1.73	1.63
Total salt consumed, oz./head/day	4.43	5.19	5.72	5.09	4.61
Average weight for the period, lbs.	602	596	577	541	546
Salt consumed-oz./1000 lbs. body wt./day	7.36	8.71	9.91	9.41	8.44

^{1/} The concentrate mixture contained 1 percent salt.

The photographs before and after treatment of steers 4 and 6 in each lot are displayed in figures 8 through 12. The steers in all lots with the possible exception of lot 5 increased in depth of body, thickness of fleshing, and quality of hair coat. The lot 5 animals increased in depth of body, but not as much as the others. The steers which received normal calcium with varying amounts of phosphorus in the ration (lots 1, 2, and 3) were superior in fleshing quality and depth of body to those which received an excess of calcium in the ration (lots 4 and 5).



Figure 6 Photographic Chute Used

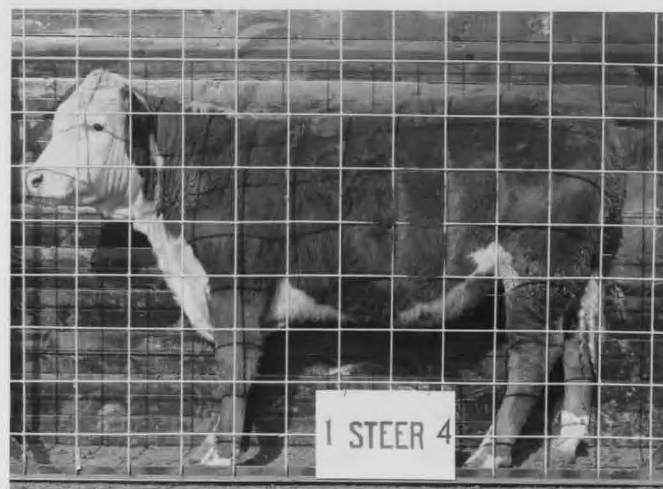


Figure 7 Photographic Chute in Operation

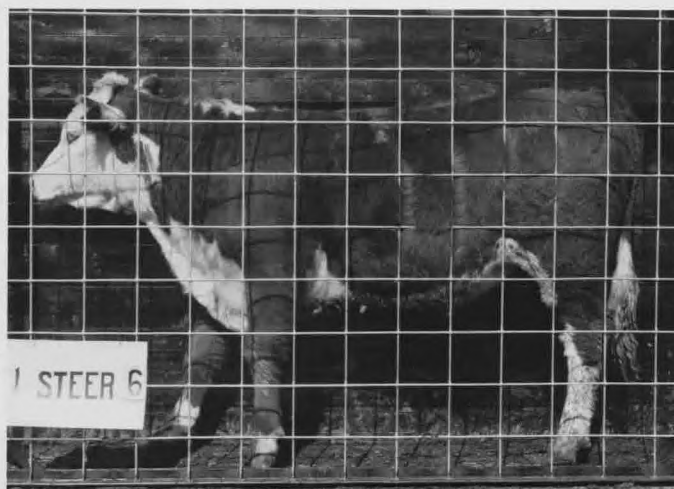
Figure 8 Representative Steers From Lot I on
Experiment I Before and After Treatment



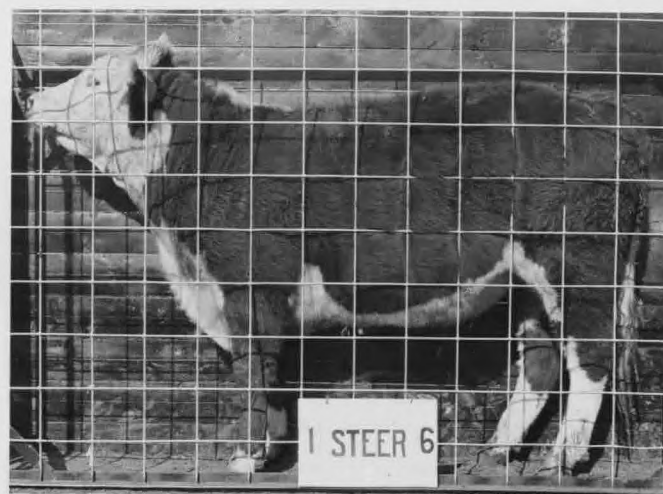
Lot I Steer 4 June 23, 1949



Lot I Steer 4 Aug. 17, 1949

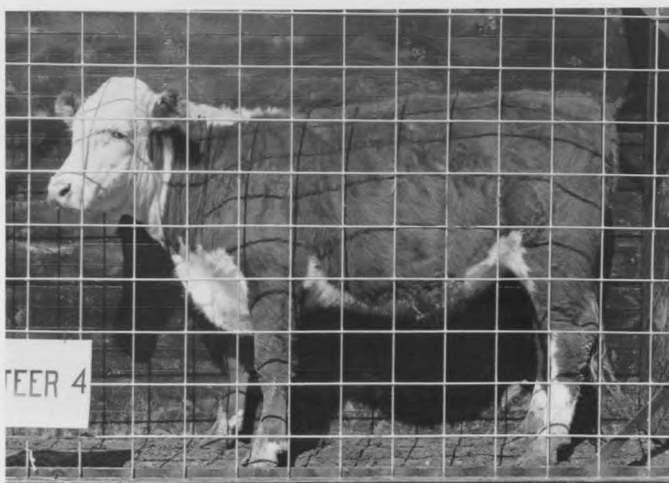


Lot I Steer 6 June 23, 1949

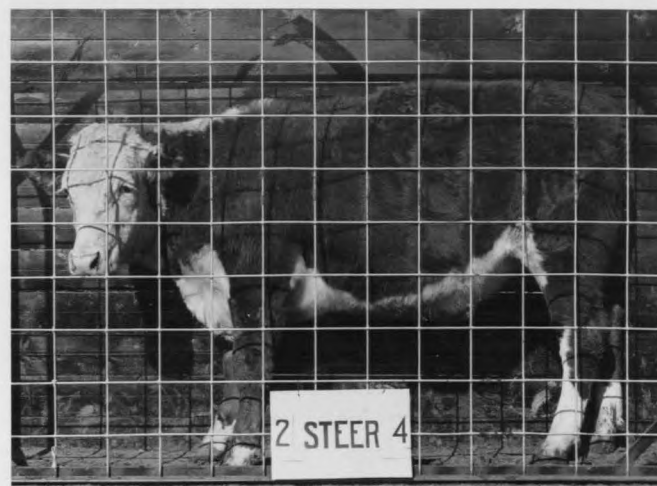


Lot I Steer 6 Aug. 17, 1949

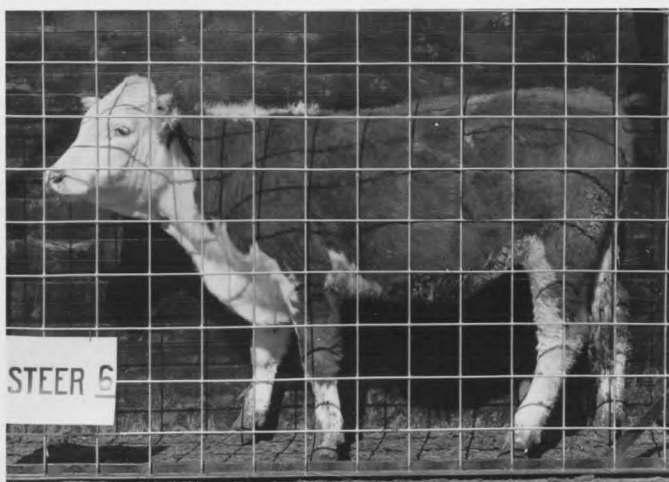
Figure 9 Representative Steers From Lot 2 on Experiment 1 Before and After Treatment



Lot 2 Steer 4 June 23, 1949



Lot 2 Steer 4 Aug. 17, 1949

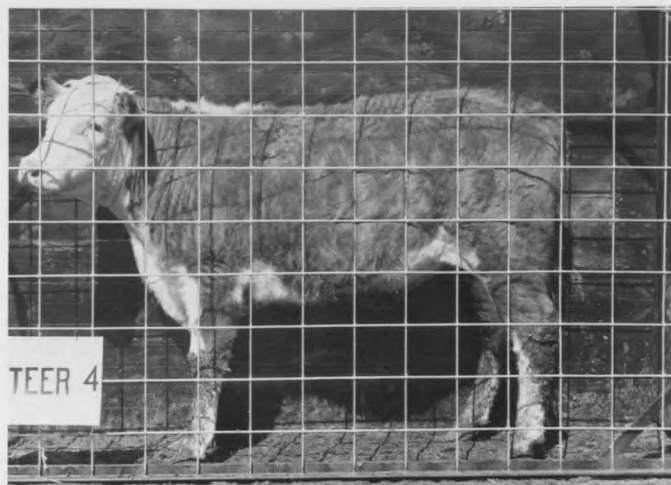


Lot 2 Steer 6 June 23, 1949

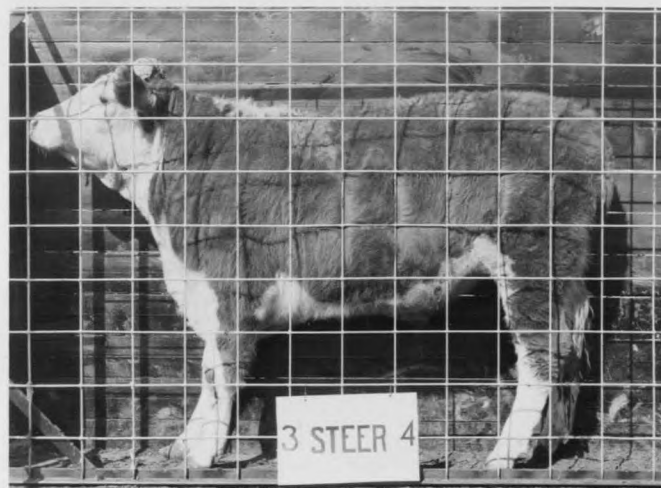


Lot 2 Steer 6 Aug. 17, 1949

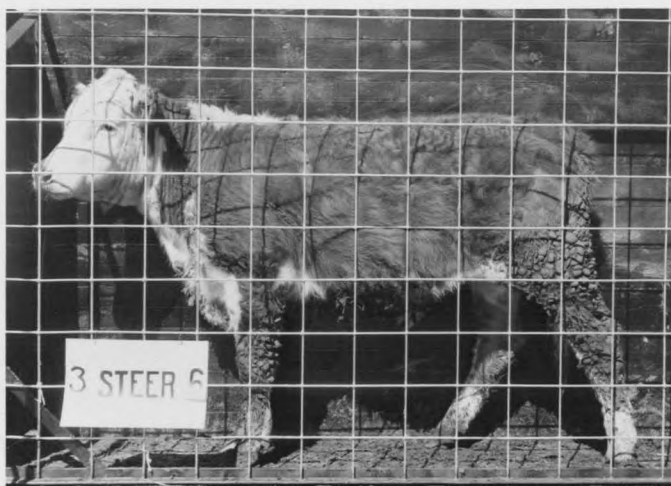
Figure 10 Representative Steers From Lot 3 on Experiment 1 Before and After Treatment



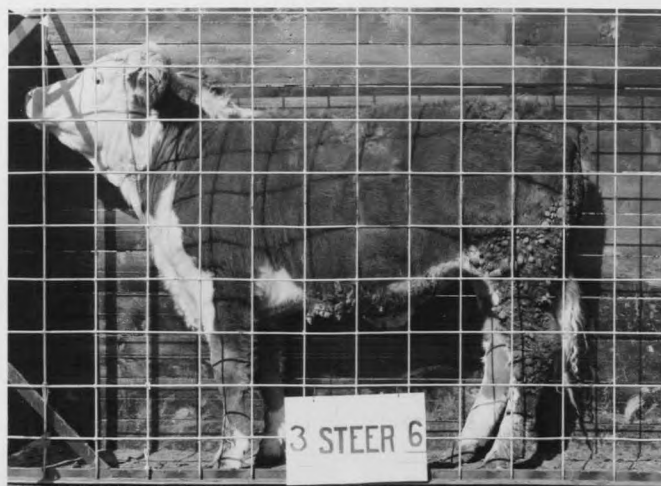
Lot 3 Steer 4 June 23, 1949



Lot 3 Steer 4 Aug. 17, 1949

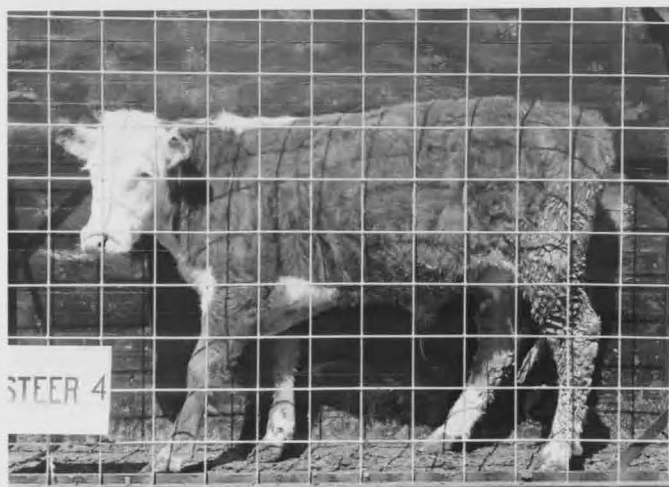


Lot 3 Steer 6 June 23, 1949

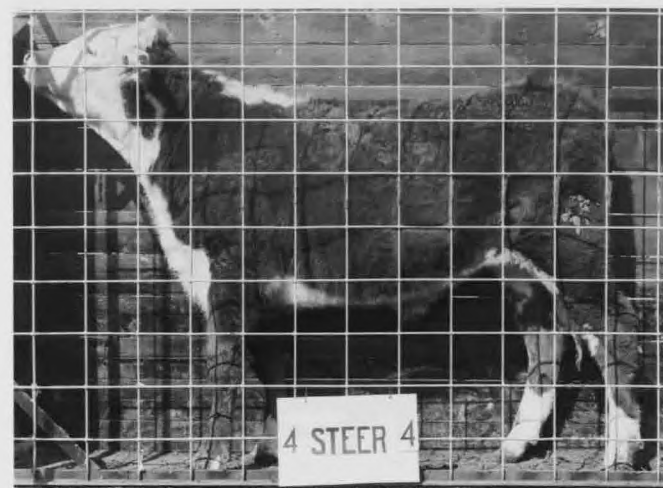


Lot 3 Steer 6 Aug. 17, 1949

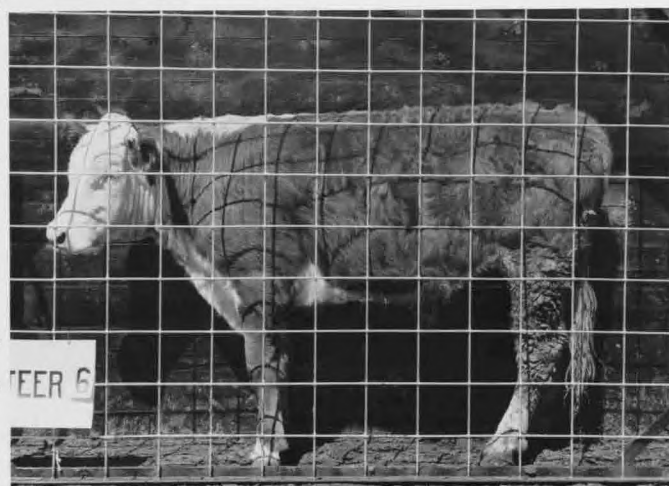
Figure 11 Representative Steers From Lot 4 on Experiment 1 Before and After Treatment



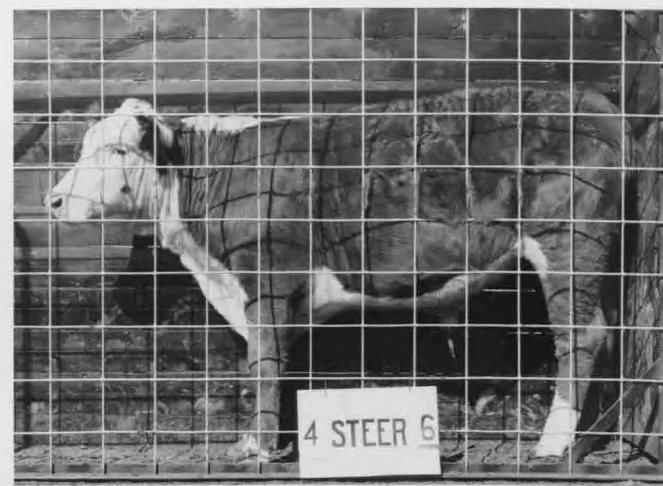
Lot 4 Steer 4 June 23, 1949



Lot 4 Steer 4 Aug. 17, 1949

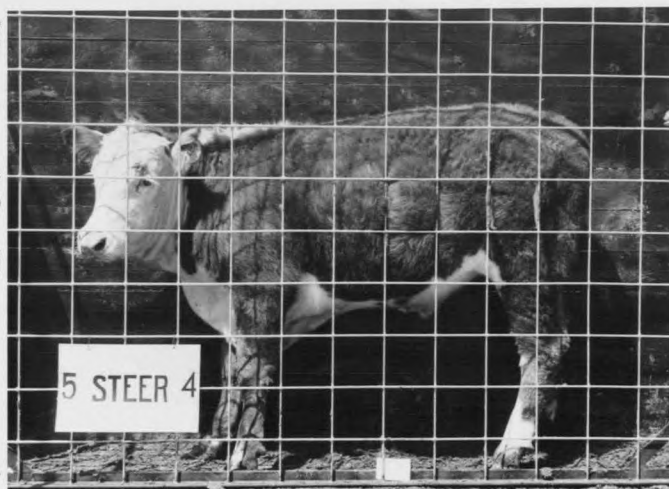


Lot 4 Steer 6 June 23, 1949



Lot 4 Steer 6 Aug. 17, 1949

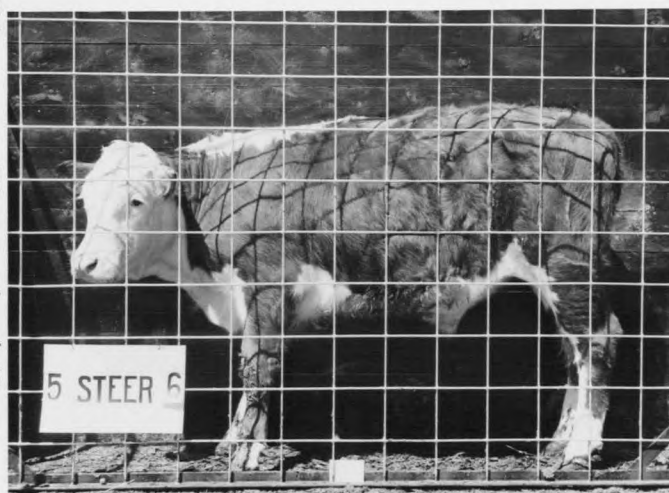
Figure 12 Representative Steers From Lot 5 on Experiment 1 Before and After Treatment



Lot 5 Steer 4 June 23, 1949



Lot 5 Steer 4 Aug. 17, 1949



Lot 5 Steer 6 June 23, 1949



Lot 5 Steer 6 Aug. 17, 1949

EXPERIMENT 2

METHODS AND PROCEDURE

Forty steer calves were randomly selected from the test herds of the U. S. Range Livestock Experiment Station at Miles City in the Fall of 1949. Eastern Montana experienced a drouth in 1949 sufficiently severe to reduce both the phosphorus content of the forage (figure 2) and the volume of forage produced to very low levels. These steer calves arrived in Bozeman by rail October 29 with clinical phosphorus and vitamin A deficiency. Four calves had vitamin A plasma levels below 10 mcg. per 100 ml. and three calves had phosphorus plasma levels below 2 mg. per 100 ml. The blood plasma determinations averaged 17.7 mcg. and 3.2 mg. per 100 ml. of vitamin A and phosphorus respectively.

The calves were given free access to salt and timothy hay containing 0.17 percent phosphorus. On November 14 the steers were graded for feeder grade and condition 3/ and 50 cc. of blood were drawn from the jugular vein for plasma calcium, phosphorus, carotene and vitamin A determinations. The steers were allotted into 5 lots of 8 steers each on the basis of weight, plasma phosphorus, feeder grade, condition score, plasma calcium, plasma vitamin A and plasma carotene. The sire groups were distributed through the lots as evenly as possible. Steers were dehorned and number branded with a hot iron for identification.

The steers were handled and accustomed to their stalls for several weeks. They were weighed and placed on the experimental rations shown

3/ F. S. Ralston, Extension Animal Husbandman, graded the calves at the beginning and at the end of the experiment.

TABLE IX. FEED AND CHEMICAL COMPOSITION OF RATIONS AS FED IN EXPERIMENT 2.

RATION NO.	I	II	III	IV	V
	%	%	%	%	%
Timothy	20.00	20.00	20.00	20.00	20.00
Beet Pulp 1/	40.00	40.00	40.00	40.00	40.00
Wheat Straw	9.80	9.80	9.80	9.80	9.80
Corn	12.00	12.00	12.00	12.00	12.00
Blood Meal	5.20	5.20	5.20	5.20	5.20
"Two-Sixty-Two" 2/	1.00	1.00	1.00	1.00	1.00
Dextrose 3/	6.00	6.00	6.00	6.00	6.00
Salt 4/	0.80	0.80	0.80	0.80	0.80
Monosodium Phosphate	0.40	0.15	—	0.15	—
Limestone	—	—	—	5.05	5.05
"Lignin" 5/	4.80	5.05	5.20	—	0.15
TOTAL	100.00	100.00	100.00	100.00	100.00
Crude Protein	12.92	12.92	12.63	12.84	13.05
T.D.N. (estimated)	60.50	60.50	60.50	60.50	60.50
Calcium	0.45	0.45	0.49	2.18	2.11
Phosphorus	0.21	0.16	0.13	0.16	0.13
Parts calcium to one part phosphorus	2.14	2.81	3.77	13.62	16.23

- 1/ Approximately 25% beet molasses had been incorporated into the beet pulp by Great Western Sugar Company, Billings, Montana.
- 2/ Urea product of E. I. Dupont De Nemours and Company, Inc.
- 3/ "Cerelese", Corn Products Sales Company, St. Paul, Minnesota.
- 4/ The following trace minerals were added to each 10 lbs. of salt at the following rates: $\text{MnSO}_4 \cdot 4\text{H}_2\text{O}$, 55.2 grams; $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, 17.8 grams; CoCO_3 , 1.0 grams. Fifty grams of lignin were added to facilitate mixing.
- 5/ By-product from production of wood molasses, supplied gratis by Forest Products Laboratory, U. S. Forest Service, Madison, Wisconsin.
- 6/ Borden's Bospro was fed every other day on top of the concentrate mixture to supply ca. 8,500 I. U. of vitamin A per day from January 20, 1950 - January 28, 1950. Thereafter, Bospro was fed to supply ca. 4,250 I. U. of vitamin A per day. Bospro was supplied gratis by The Borden Company, Chicago, Illinois.

in Table IX 9/ at the evening feeding on December 27, 1950. These rations were identical except for different amounts of calcium, phosphorus and lignin. The lignin was used as a filler and was assumed to be inert. A digestion trial conducted in April 1950 confirmed this assumption. 10/ Ration 1 was considered to contain adequate but not excessive amounts of calcium and phosphorus. (National Research Council, 1945) Ration 2 was considered to be borderline in phosphorus content (Beeson et al., 1941) and contained the same amount of calcium as ration 1. Ration 4 was the same as ration 2 except that an excess of limestone was added. Ration 3 was deficient in phosphorus (Beeson et al., 1941) and contained the same calcium as ration 1. Ration 5 was the same as ration 3 except that an excess of limestone was added. Lot 1 served as a control. The effect of adding an excess of limestone to the ration of the calves was studied by comparing lots 2 and 4 and lots 3 and 5.

The rations were supplemented with approximately 17,000 I. U. of vitamin A and 4,760 I. U. of vitamin D per head fed every other day on top of the concentrate mixture from January 20 to January 28 in the form of Borden's Bospro 11/, a dry stabilized vitamin A-D supplement with a guaranteed potency of 125,000 I. U. of vitamin A and 70,000 I. U. of vitamin D per pound, but with a claimed effective potency of 250,000 I. U. A and 70,000 I. U. D per pound due to the addition of Neo-phosphatin (a specially prepared lecithin made by The Borden Company). These steers

9/ The experimental rations were mixed in a 1000 pound batch mixer at the Poultry Farm, under the direction of experiment station personnel, using ingredients of known chemical composition.

10/ The details of this digestion trial are given on page 86.

11/ Borden's Bospro was supplied gratis by The Borden Company.

were supplemented on the basis of the effective potency. From January 28 until the end of the trial, approximately 8,500 I. U. of A and 2,380 I. U. of D per head were supplied every other day. All rations were supplemented with manganese, copper and cobalt as shown in Table IX, to guard against a possible deficiency of any of these elements.

The steers were individually fed according to appetite for 120 days and the weighback recorded. At 28 day intervals the steers were weighed and 50 cc. of blood drawn from the jugular vein for calcium and phosphorus determinations. Plasma vitamin A and carotene determinations were made at the beginning and plasma carotene determinations were made at the end of the experiment. ^{12/} Individual photographs were made in a measuring chute at the beginning and at the end of the trial. Feeder grade and condition were determined at the end of the experiment. All lots were bedded with wood shavings. Samples of the concentrate mixtures were taken as they were fed and analyzed each 28 days for protein, calcium, and phosphorus. Hay samples were taken as the hay was fed and analyzed at the middle and end of the trial for protein, calcium, phosphorus and carotene. The weighbacks were pooled within each lot and the lot weighback analyzed each 28 days for moisture, protein, calcium and phosphorus.

The steers were continued on the experimental rations as usual from April 28 until May 26 (28 days) with the exception that three steers from both lot 3 and lot 5 were given a daily drench of about 15 grams of phosphorus supplied from 59 grams of monosodium phosphate dissolved in water to make 12 ounces of solution. For convenience these six steers were ^{12/} The vitamin A determinations were spoiled.

placed in lot 5, although maintained on their same rations, and the undrenched steers, fed their usual rations were grouped in lot 3.

The steers were removed from the feeding trial on May 26 and were accustomed to a ration of barley, beet pulp, and corn. On June 1 the steers were put out on a 15 acre irrigated pasture seeded to modified Huntley mixture with free access to a mineral supplement containing 16 percent phosphorus ^{13/} and to a self feeder containing one-third barley, one-third beet pulp and one-third corn. The only salt supplied for the first 56 days on pasture was the 10 percent contained in the mineral supplement. The steers were weighed on June 29 and July 27, and are to be continued on grain and grass with mineral supplementation until fall, to study the effect of the various rations fed during the winter on the summer performance of these animals. Feed and mineral consumption, 28 day weights, final grade and condition, and selling price will be recorded for each animal. The data obtained during the first two weigh periods are reported in this thesis.

^{13/} Misco mineral supplied gratis by the Misco Mills division of Centennial Flouring Mills, Co., Bozeman, Montana.

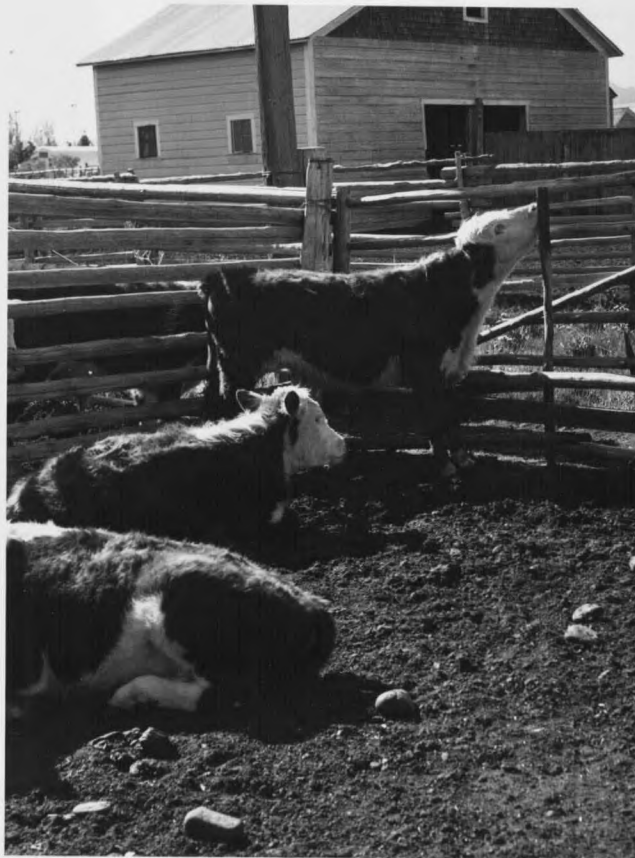


Figure 13 Wood Chewing by a Phosphorus Deficient Steer

RESULTS AND DISCUSSION

Notes and Comments

The steers fed rations 3, 4, and 5 were difficult to get on feed. Minute amounts of ground anise seed were added to these rations at intervals to induce better consumption. Steer 4 in lot 5 refused to eat any concentrate, even rolled oats. Steer 4 in lot 3 was very slow in starting on feed and was hard to keep on feed. He consistently refused everything except small amounts of rolled oats and hay after February 27. Both steers were removed from the lots March 25, after all efforts to get them on feed had failed. Their records were not considered in any of the tabulations.

Wood chewing was observed in all lots after 27 days on the experimental rations. Figure 13 shows a lot 3 steer persistently chewing a pole. Figures 14 and 15 present mute evidence of depraved appetite in lot 3. Such early appearance of pica was probably due to the finely divided state in which the rations were fed. (Theiler et al., 1937; Eveleth, 1949) However, pica was not as pronounced in lots receiving adequate and borderling phosphorus with normal calcium as it was in the other lots. Lots receiving deficient levels of phosphorus were especially persistent pole chewers.

Beeson, Bolin, Hickman, and Johnson (1941) did not encounter depraved appetite until after 112 days on a phosphorus deficient ration. Slight stiffness of the hind legs was noted in the lots fed excessive amounts of limestone after 57 days on the experimental rations. It was first noted on February 23 and was observed until early in April. The hocks became swollen and the knees enlarged. The stiffness gradually disappeared with



Figure 14 The Barn Wall Partially Eaten by Phosphorus Deficient Steers



Figure 15 Well-gnawed Corral Poles

the advent of warmer weather and more sunshine and was not noticed after April 14. However, the hocks and knees remained enlarged throughout the trial. A few of the steers in lot 3 were stiff during this period, but were not affected as badly as those in lots 4 and 5. Edema of the hocks and knees was detected in lot 3 after about 70 days on the experimental rations.

All of the steers were quite heavily infected with lice and warbles. They were sprayed with rotenone by the Entomology Department on March 15, 1950.

Steer 6 in lot 1 had fever of undetermined origin and was off feed from April 3 until April 14. The steer recovered without treatment. Steer 3 in lot 1 went off feed on May 2 and developed severe incoordination which continued until he went onto pasture. The steer recovered on pasture and made slightly better than the average gain for the lot during both periods. The terminal carotene plasma level was 105 microgram per 100 ml. However, the records of this steer were not used in tabulating the data for period 5 or in computing the performance of the steers on pasture.

Feed Consumption

The chemical composition of the rations fed in Experiment 2 was very constant throughout the period (Tables XI-XV). However, the concentrate mixture was not pelleted and did not contain any binding agent such as molasses which could have prevented the steers from separating out the unpalatable material. During the last two weigh periods the steers in lots 4 and 5 had very poor appetites and were able to separate the limestone out of the mixture and leave it in the weighback. These weighbacks

TABLE X. PERFORMANCE OF STEERS ON EXPERIMENT 2 MEASURED OVER THE FIRST 120 DAYS (December 27, 1949 to April 28, 1950)

ITEMS MEASURED	LOT				
	I	II	III	IV	V
Number of steers	8	8	7	8	7
Phosphorus in ration, %	0.20	0.16	0.14	0.16	0.14
Calcium in ration, %	0.47	0.46	0.50	1.56	1.41
Parts calcium to one part phosphorus	2.27	2.80	3.63	9.92	10.34
Phosphorus intake-grams/100 lbs. body wt./day	2.04	1.65	1.27	1.40	1.15
Calcium intake-grams/100 lbs. body wt./day	4.63	4.62	4.61	13.94	11.91
Initial weight, lbs.	314	301	302	311	316
Feed consumed/100 lbs. body wt./day	2.19	2.20	2.01	1.96	1.87
Average daily gain, lbs.	1.41	1.07	0.40	0.68	0.45
Feed per 100 lbs. gain, lbs.	623	763	1993	1051	1472
Terminal calcium plasma level, mg. %	10.2	11.0	11.1	10.8	10.9
Terminal phosphorus plasma level, mg. %	6.4	3.1	2.5	3.0	2.6

TABLE XI. PERFORMANCE OF STEERS ON EXPERIMENT 2 IN LOT 1 AS MEASURED BY WEIGH PERIODS

ITEMS MEASURED	PERIODS				
	I	II	III	IV	V
Number of steers	8	8	8	8	7
Phosphorus in ration, %	0.20	0.21	0.21	0.20	0.21
Calcium in ration, %	0.49	0.47	0.45	0.45	0.42
Parts calcium to one part phosphorus	2.51	2.24	2.12	2.21	1.99
Phosphorus intake-grams/100 lbs. body wt./day	2.06	2.33	2.13	1.81	1.83
Calcium intake-grams/100 lbs. body wt./day	5.05	5.22	4.53	4.00	3.64
Initial weight, lbs.	314	349	390	438	478
Feed consumed/100 lbs. body wt./day	2.31	2.44	2.23	1.97	1.91
Average daily gain, lbs.	0.97	1.46	1.65	1.64	1.46
Feed per 100 lbs. gain, lbs.	916	653	618	566	649
Calcium plasma level mg. %	8.9	9.8	8.3	10.2	11.7
Phosphorus plasma level mg. %	5.8	6.0	5.6	6.4	6.5

TABLE XII. PERFORMANCE OF STEERS ON EXPERIMENT 2 IN LOT 2 AS MEASURED BY WEIGH PERIODS

ITEMS MEASURED	PERIODS				
	I	II	III	IV	V
Number of steers	8	8	8	8	8
Phosphorus in ration, %	0.16	0.15	0.15	0.19	0.15
Calcium in ration, %	0.48	0.46	0.45	0.43	0.40
Parts calcium to one part phosphorus	3.03	2.98	2.97	2.25	2.62
Phosphorus intake-grams/100 lbs. body wt./day	1.72	1.73	1.40	1.55	1.14
Calcium intake-grams/100 lbs. body wt./day	5.21	5.14	4.16	3.49	3.03
Initial weight, lbs.	301	346	381	410	429
Feed consumed-lbs./100 lbs. body wt./day	2.38	2.48	2.02	1.78	1.66
Average daily gain, lbs.	1.25	1.25	1.01	0.68	1.21
Feed-lbs./100 lbs. gain	624	790	1110	1197	612
Calcium plasma level mg. %	8.8	10.2	9.2	11.0	12.2
Phosphorus plasma level mg. %	3.9	3.7	3.2	3.1	3.5

TABLE XIII. PERFORMANCE OF STEERS ON EXPERIMENT 2 IN LOT 3 AS MEASURED BY WEIGH PERIODS

ITEMS MEASURED	PERIOD					
	I	II	III	IV	V undrenched	V drenched ^{1/}
Number of steers	7	7	7	7	4	3
Phosphorus in ration, %	0.14	0.13	0.14	0.14	0.14	0.46
Calcium in ration, %	0.48	0.45	0.60	0.48	0.41	0.44
Parts calcium to one part phosphorus	3.35	3.45	4.41	3.53	3.03	0.94
Phosphorus intake-grams/100 lbs. body wt./day	1.55	1.33	1.01	0.91	0.94	3.87
Calcium intake-grams/100 lbs. body wt./day	5.20	4.58	4.47	3.23	2.85	3.65
Initial weight, lbs.	320	345	365	382	341	403
Feed consumed-lbs./100 lbs. body wt./day	2.37	2.22	2.23	1.48	1.54	1.84
Average daily gain, lbs.	0.70	0.71	0.59	-0.52	1.08	3.04
Feed-lbs./100 lbs. gain	1341	1184	1961	—	506	271
Calcium plasma level mg. %	9.3	10.4	9.2	11.1	12.4	12.2
Phosphorus plasma level mg. %	3.0	2.9	2.5	2.5	2.8	7.1

^{1/} These steers were drenched with about 15 grams of phosphorus daily from monosodium phosphate.

TABLE XIV. PERFORMANCE OF STEERS ON EXPERIMENT 2 IN LOT 4. AS MEASURED BY WEIGH PERIODS

ITEMS MEASURED	PERIODS				
	I	II	III	IV	V
Number of steers	8	8	8	8	8
Phosphorus in ration, %	0.16	0.15	0.15	0.16	0.16
Calcium in ration, %	1.45	1.79	1.33	1.66	2.42
Parts calcium to one part phosphorus	9.09	11.70	8.63	10.22	15.06
Phosphorus intake-grams/100 lbs. body wt./day	1.70	1.54	1.16	1.09	1.04
Calcium intake-grams/100 lbs. body wt./day	15.39	18.12	14.46	11.26	15.86
Initial weight, lbs.	311	334	362	384	392
Feed consumed-lbs./100 lbs. body wt./day	2.34	2.22	2.02	1.49	1.43
Average daily gain, lbs.	0.62	1.00	0.79	0.26	0.74
Feed-lbs./100 lbs. gain	1853	794	825	1812	777
Calcium plasma level mg. %	9.1	10.9	9.3	10.8	12.4
Phosphorus plasma level mg. %	3.0	3.6	2.9	3.0	3.0

TABLE XV. PERFORMANCE OF STEERS ON EXPERIMENT 2 IN LOT 5 AS MEASURED BY WEIGH PERIODS

ITEMS MEASURED	I	II	III	IV	V	V
					undrenched	drenched ^{1/}
Number of steers	8	8	8	8	4	3
Phosphorus in ration, %	0.14	0.13	0.13	0.13	0.13	0.45
Calcium in ration, %	1.50	1.84	0.86	1.16	2.12	2.32
Parts calcium to one part phosphorus	10.37	13.80	6.59	8.89	16.07	5.13
Phosphorus intake-grams/100 lbs. body wt./day	1.50	1.28	0.90	0.83	0.71	4.00
Calcium intake-grams/100 lbs. body wt./day	15.47	17.62	6.00	7.71	11.52	20.52
Initial weight, lbs.	316	329	356	361	351	396
Feed consumed-lbs./100 lbs. body wt./day	2.28	2.11	1.52	1.43	1.19	1.95
Average daily gain, lbs.	0.36	0.96	0.17	0.32	0.45	2.12
Feed-lbs./100 lbs. gain	1456	883	1769	2377	956	392
Calcium plasma level mg. %	9.3	11.4	9.2	10.9	12.8	12.2
Phosphorus plasma level mg. %	2.7	2.9	2.5	2.6	2.6	7.2

^{1/} These steers were drenched with about 15 grams of phosphorus daily from monosodium phosphate.

were pooled and analyzed by lots. Since there were no individual measurements of calcium and phosphorus intake when feed was weighed back, no statistical analyses of the relationships of calcium and phosphorus intake were possible.

Figure 16 shows the suboptimal feed consumption obtained on these simplified rations. Feed consumption declined after 64 days on experiment irrespective of the treatment. Those steers fed normal calcium with adequate or borderline phosphorus in the ration ate more during the second period, but their consumption declined thereafter. A comparison of figure 16 with Table I shows that at no time did the consumption closely approach the recommendations of the National Research Council. This poor feed intake may have been due to the physical condition of the ration or to unpalatability.

Reduced feed consumption was especially striking in those steers fed rations 3, 4, and 5. Table X shows the feed consumed per 100 lbs. body weight per day by the various lots during the first 120 days on experiment. The animals in lot 2 receiving a borderline level of phosphorus (0.16%) with normal calcium consumed as much feed per unit of weight as did those animals fed a ration which was adequate in both calcium and phosphorus. The excess limestone fed to the lot 4 steers reduced their feed consumption 10.9% as compared with the lot 2 steers. The reduced feed consumption was probably partly due to the reduced phosphorus intake resulting from reduced feed consumption. The excess limestone in ration 5 depressed the feed consumption 7.0% as compared with lot 3 fed a normal calcium-deficient phosphorus ration. The low phosphorus ration fed to lot 3 lowered the feed consumption

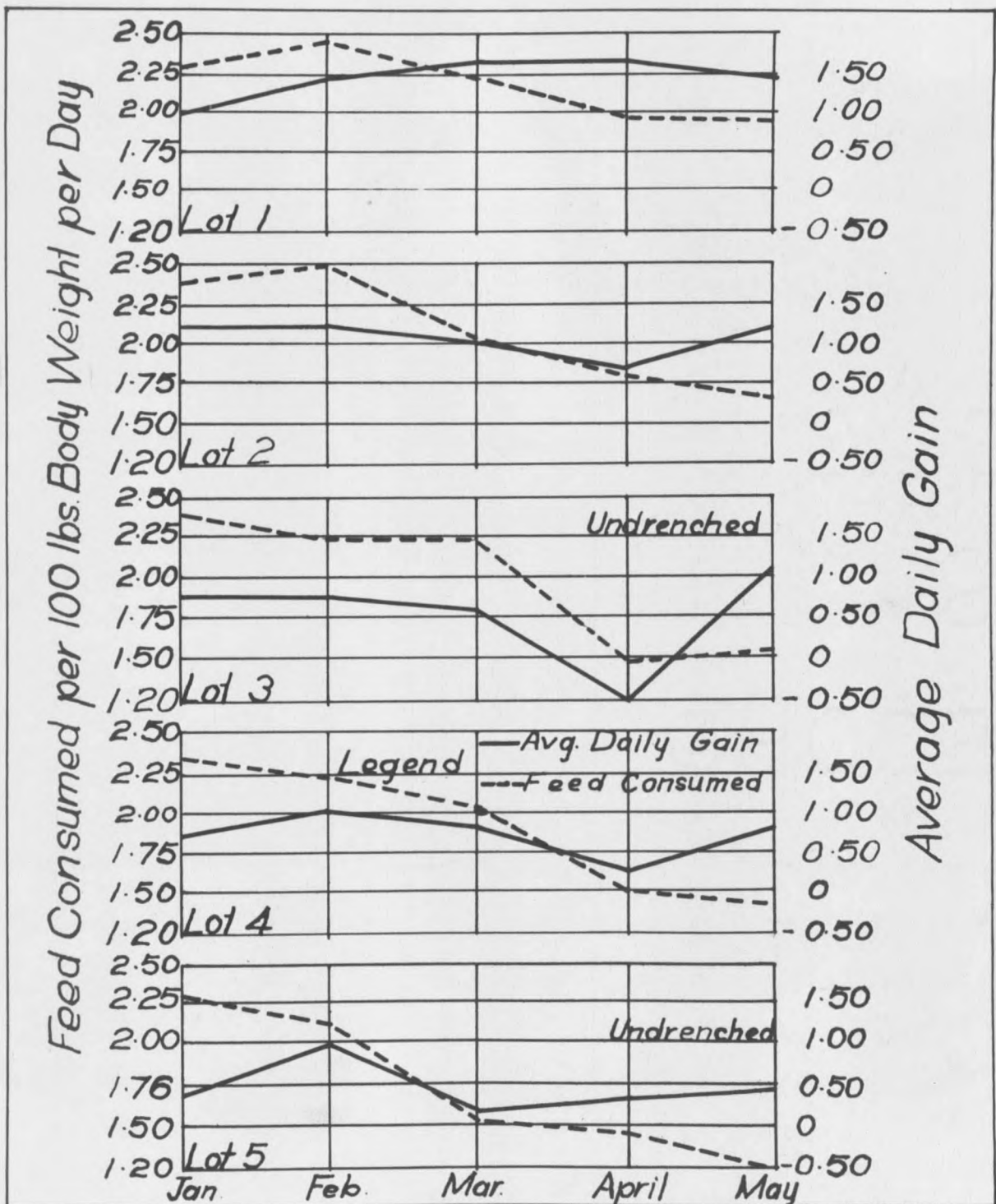


Fig. 16. Feed Consumption and Weight Gains of the Steers on Experiment 2 by Weigh Periods

8.2 percent as compared with lot 1.

These data show that a phosphorus deficiency reduced the feed consumption. The addition of excess limestone to the deficient ration accentuates the reduction. The addition of excess limestone to a ration borderline in phosphorus content causes a reduction in feed consumption which is not due to the borderline level of phosphorus in the ration. The reduced feed consumption on the high limestone rations may be explained on the basis of unpalatability, interference with phosphorus absorption or metabolism, or by the effect of the calcium itself on the appetite.

Rate of Gain

The rate of gain achieved in this trial is in no way comparable to usual feed lot performance. The ration used was strictly an experimental ration designed to promote normal growth but not to fatten (compare Table I and Table IX). This ration was a simplified ration which contained several ingredients which are not palatable to cattle. Poor feed consumption was achieved even by the control animals. Also, the frequent handling and the nervousness induced by periodic bleeding were not conducive to the best gains.

Table X summarizes the weight gains by lots for the first 120 days of the experiment. The average rate of gain of the various lots by weight periods is shown in figures 16 and 17. ^{14/} The gains made by the control animals were only slightly below the expectations for normal growth (Table I). The borderline level of phosphorus fed to lot 2 reduced the

^{14/} The data entered in figure 16 and 17 for lots 3 and 5 for May are from undrenched animals only.

average daily gain 24 percent without affecting the feed consumption. These animals carried just as much finish and were just as "typey" as those in lot 1. (Table XVII) If these steers had not been compared with the controls, it is probable that the production-cutting effect of the borderline phosphorus intake would not have been detected.

The excess limestone fed to the lot 4 steers reduced the average daily gain 36 percent as compared with lot 2.

The high calcium, deficient phosphorus ration fed to lot 5 did not depress the weight gains any further than the normal calcium-deficient phosphorus ration fed to lot 3. These 2 lots gained only about 30 percent as much as the controls. All of the lot 3 steers lost weight during the fourth period. However, during the fifth period, the undrenched animals in lot 3 gained an average of one pound per head per day.

Figure 16 indicates a fairly close relationship between rate of gain and feed consumption. The correlation coefficient between feed consumed per 100 pounds body weight per day and average daily gain is 0.640 . When all lots were adjusted to a constant feed intake by covariance, the differences in the lot means for rate of gain were still significant at the 1 percent level. (Snedecor, 1946) A much stronger relationship between feed consumption and rate of gain was indicated in Experiment 1. However, the relationship studied in Experiment 1 was between total feed consumed over the period and total gain over the period. Since the steers that gained the most had the highest average weight and generally consumed the most feed, a high correlation between total feed intake and gain was obtained.

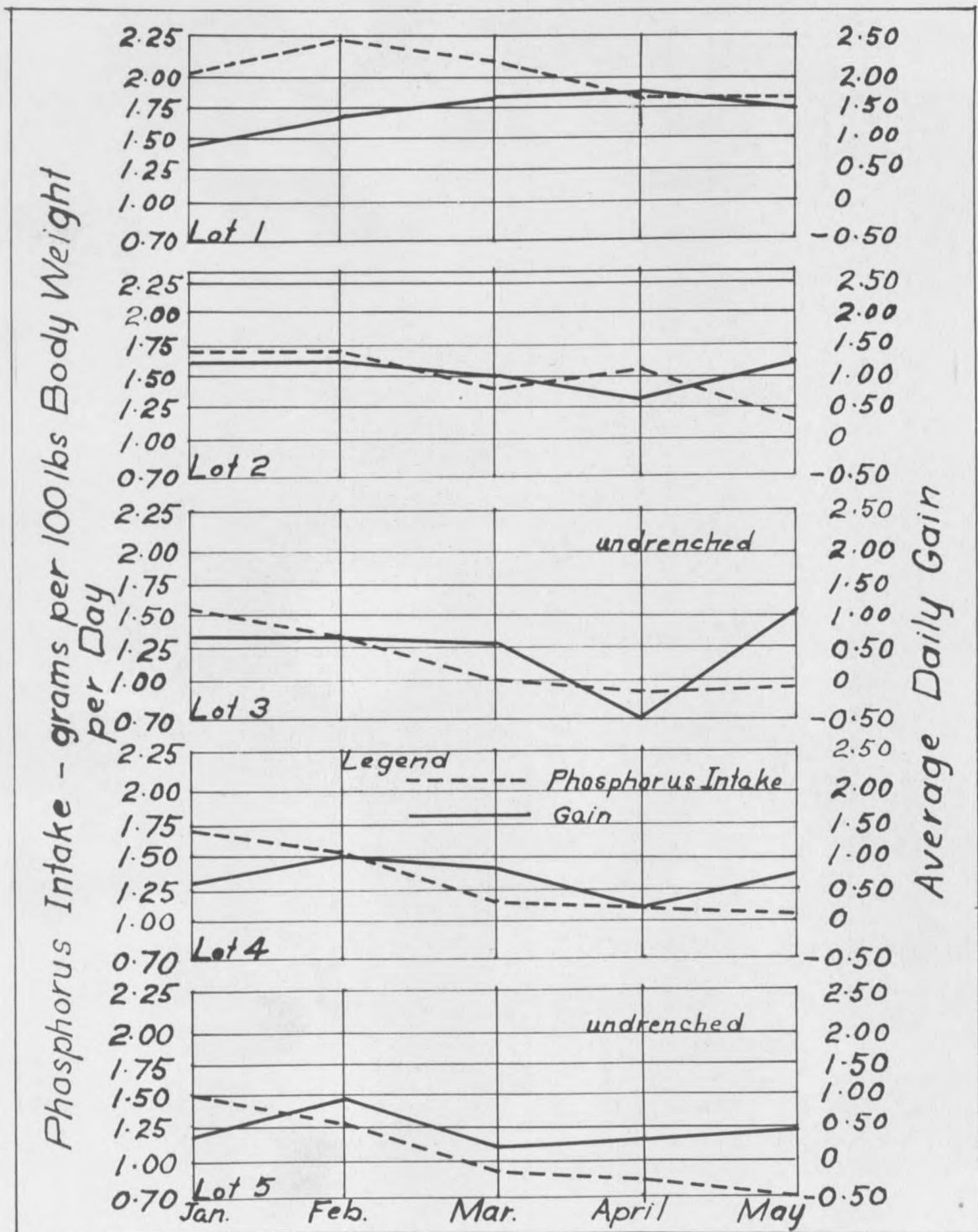


Fig. 17. Phosphorus Intake and Weight Gains of the Steers on Experiment 2 by Weigh Periods

The relationship of phosphorus intake and average daily gain is indicated graphically by lots in figure 17. No statistical analyses were made. The increases in rate of gain shown for the month of May in figures 16 and 17 for all lots except the control lot, is unexplained.

These data show that a borderline phosphorus deficiency may seriously reduce the rate of gain. The addition of excess limestone to a ration with borderline phosphorus intake caused a further reduction in rate of gain. Phosphorus deficiency reduced the rate of gain as much as 70 percent. The addition of excess limestone to a phosphorus deficient ration caused no further reduction in the rate of gain.

Efficiency of Feed Utilization

This experiment was not designed to study the effect of the various treatments on the efficiency of feed utilization, because the animals in this experiment were fed according to appetite, and the feed consumption varied widely. However, the animals in lots 1 and 2 consumed essentially the same amount of feed per 100 pounds of body weight during the first 120 days of the trial (Table X). Seven hundred sixty three pounds of the borderline phosphorus ration were needed to produce 100 pounds of gain whereas only 623 pounds of the adequate phosphorus ration were required. Table X also shows that the steers fed the excess limestone in ration 5 ate less and gained slightly more than the steers in lot 3. The feed efficiency of lots 3 and 5, which differ in feed consumption per 100 pounds of body weight by only 7 percent are 1993 pounds and 1472 pounds per 100 pounds gain respectively. Tables XI through XV indicate that feed efficiency was not affected until after 64 days on the experimental rations.

These data have not been tested for significance.

Blood Chemistry

Calcium and Phosphorus

The calcium and phosphorus plasma levels are shown in Tables XI-XV by lots and by weigh periods. Figure 19 gives the same information graphically. Figure 18 shows the relationship between phosphorus intake and plasma phosphorus. These data show that there is a general relationship between phosphorus intake and phosphorus plasma level. However, the excess limestone added to rations 4 and 5 reduced the phosphorus intake without materially affecting the plasma phosphorus. The excess calcium in the ration lowered the performance of lot 4 as compared with lot 2, but the excess calcium in ration 5 did not depress the performance of lot 5 as compared with lot 3.

It has been commonly thought that calcium and phosphorus were in equilibrium in the bones and in the blood stream, and that a lowering of the plasma phosphorus would cause an increase in the plasma calcium. (Best and Taylor 1945; Dukes, 1947) These data show that the calcium plasma level was largely independent of the phosphorus plasma level and was affected very little by the lot treatments. Figure 19 shows the characteristic pattern of fluctuation of plasma calcium in all lots by weigh periods. This consistent pattern of fluctuation, independent of lot treatments, is unexplained.

Carotene

Table XVI shows the response of the plasma carotene to variations in calcium and phosphorus intake. All lots received approximately 8,500 I. U.

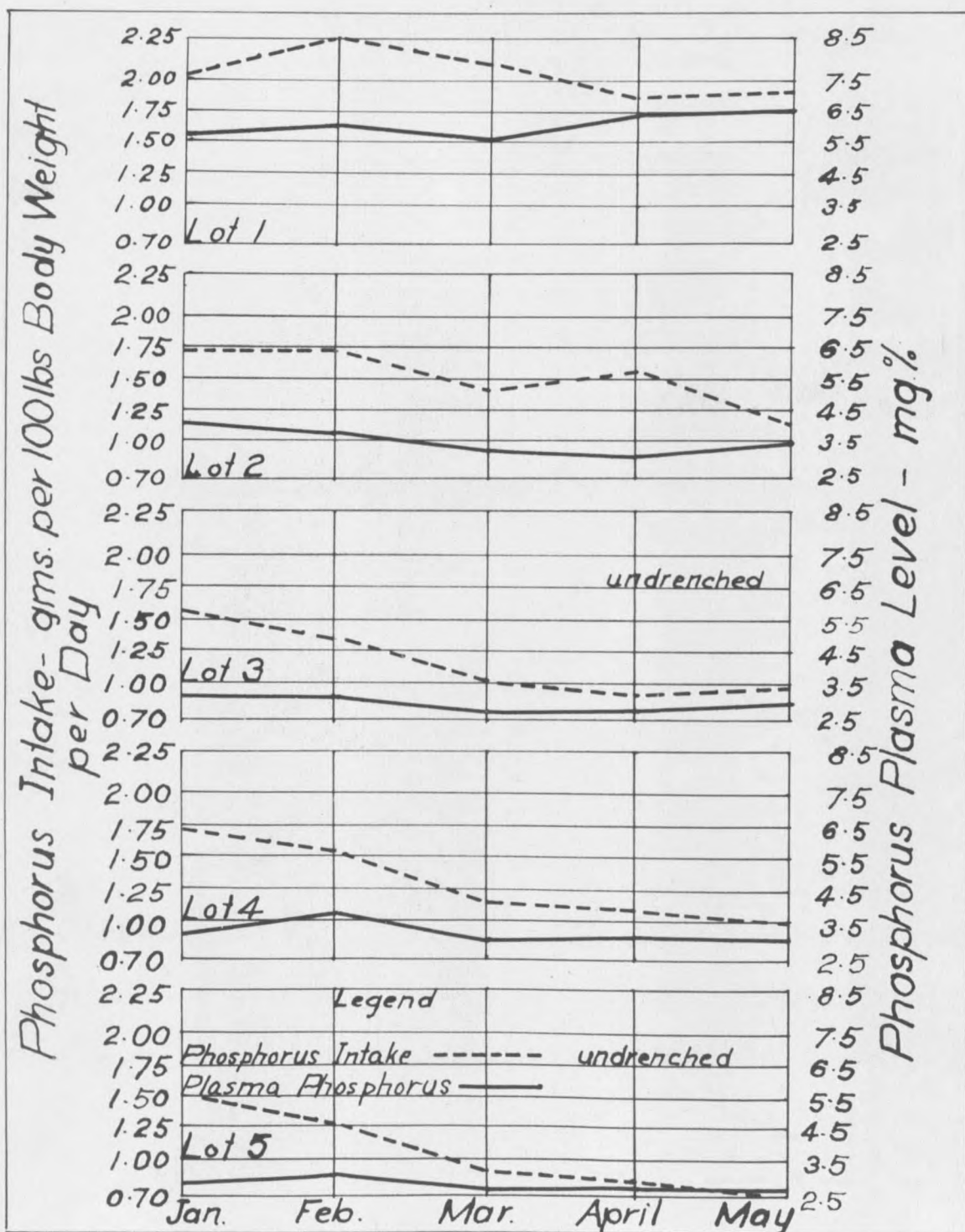


Fig. 18. Phosphorus Intake and Phosphorus Plasma Levels of the Steers on Experiment 2 by Weigh Periods

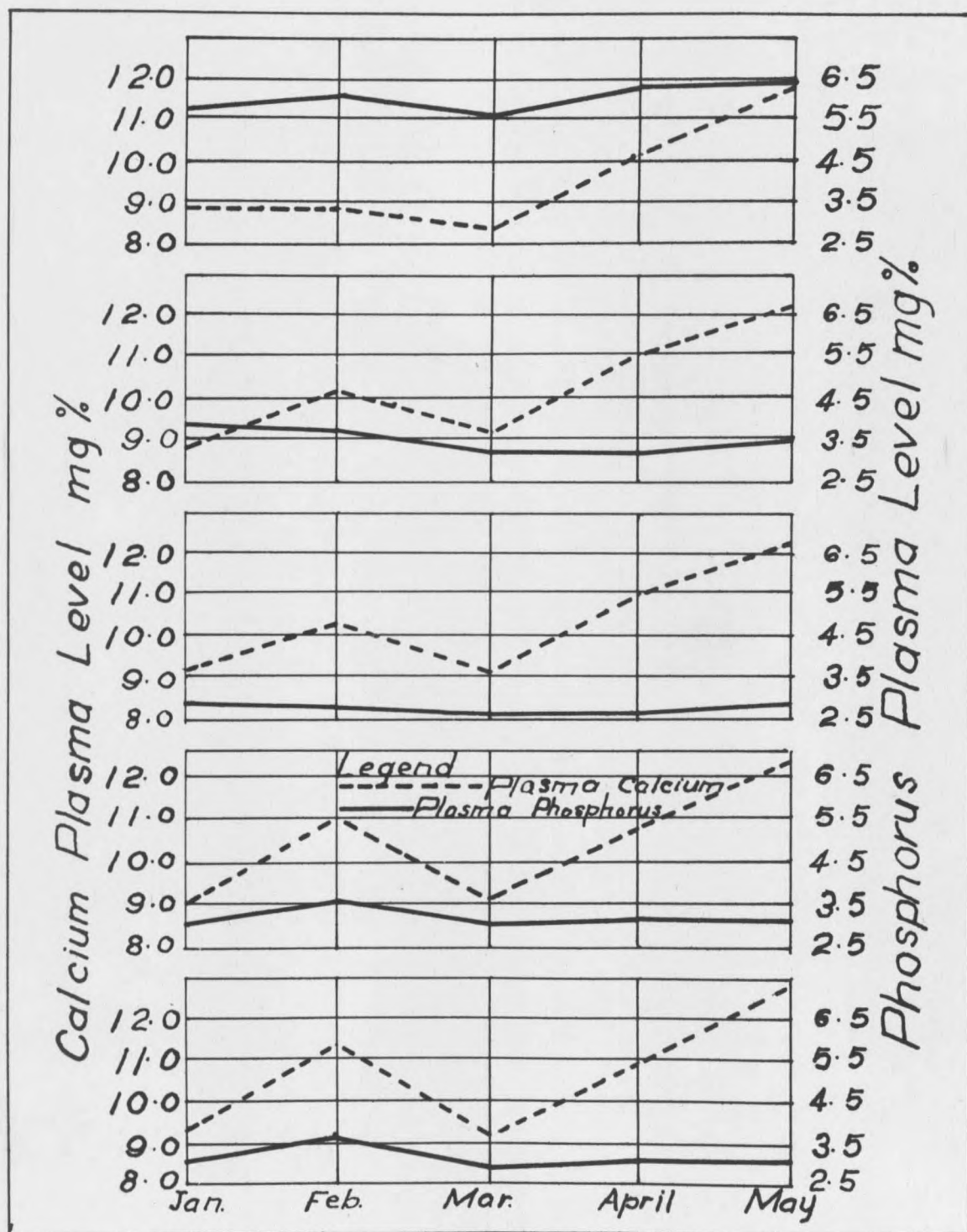


Fig. 19. Calcium and Phosphorus Plasma Levels of the Steers on Experiment 2 by Weigh Periods

TABLE XVI. EFFECT OF THE EXPERIMENTAL RATIONS ON THE CAROTENE PLASMA LEVELS OF THE STEERS ON EXPERIMENT 2.

LOTS	I	II	III undrenched	III drenched ^{1/}	IV	V undrenched	V drenched ^{1/}
Number of steers	7	8	3	3	8	4	3
Carotene consumed during period, mgs./head/day	10.07	9.87	9.50	10.77	9.87	9.38	10.77
Phosphorus intake-gms./ 100 lbs. body wt./day during May	1.83	1.14	0.94	3.87	1.04	0.71	4.00
Plasma phosphorus, May 26, mg. %	6.5	3.5	2.8	7.1	3.0	2.6	7.2
Plasma carotene February 1st, mcg. %	73.6	61.2	68.3	66.7	48.8	53.8	55.0
Plasma carotene May 26, mcg. %	85.7	101.2	91.7	78.3	107.5	111.2	68.3
Change in plasma carotene mcg. %	12.1	32.9	23.4	11.6	58.7	57.4	13.3

^{1/} These steers were drenched with about 15 grams of phosphorus daily from monosodium phosphate.

of vitamin A per head every other day in the form of Borden's Bospro. Those steers which had the highest phosphorus intake also consumed the most carotene in the form of hay. However, the calves which received adequate or more than adequate levels of phosphorus showed smaller increases in plasma carotene than did the steers on deficient intakes of phosphorus. The steers which were drenched with large amounts of phosphorus during the month of May showed about the same increase in plasma carotene as did the control steers in lot 1. This indicates either that the large doses of phosphorus were not continued long enough to fully depress the carotene of the plasma or that adequate and excessive levels of phosphorus depress the plasma carotene to the same degree. Excess calcium in the ration appears to be associated with higher carotene blood levels in addition to its phosphorus relationships. The plasma carotene of lots 4 and 5 showed a similar response even though the phosphorus intake was 32 percent lower in lot 5 during the month of May. These data show that deficient phosphorus in the ration is associated with a greater increase in plasma carotene than adequate phosphorus. An excess of calcium in the ration seems to be associated with higher plasma carotene values. These findings are in agreement with those of Ross and Gallup (1949) who report an inverse relationship between phosphorus and carotene in the plasma of cattle.

Feeder Grade and Condition

These data are based on visual appraisal of the calves by the same man on occasions six months apart. The differences indicated in Table XVII, although small, are quite suggestive. These calves were phosphorus and vitamin A deficient when they were graded on November 14. During the

TABLE XVII. EFFECT OF EXPERIMENTAL RATIONS ON THE FEEDER GRADE AND CONDITION 1/ OF THE STEERS ON EXPERIMENT 2 2/

LOTS	I	II	III	IV	V
Feeder Grade, Nov. 14	9.3	9.2	9.6	9.8	10.0
Feeder Grade, May 22	7.1	7.0	8.9	9.2	11.4
Change in Feeder Grade	-2.2	-2.2	-0.7	-0.6	+1.4
Condition Score, Nov. 14	4.7	4.4	5.1	4.8	4.9
Condition Score, May 22	5.0	5.1	6.7	7.4	6.9
Change in Condition Score	+0.3	+0.7	+1.6	+2.6	+2.0

1/ Steers were graded on the basis of eighteen Feeder Grades:

Fancy 1, 2, 3.
 Choice 4, 5, 6.
 Good 7, 8, 9.
 Medium 10, 11, 12.
 Common 13, 14, 15.
 Inferior 16, 17, 18.

and nine Condition Classes:

Good 1, 2, 3.
 Fair 4, 5, 6.
 Poor 7, 8, 9.

in accordance with the U. S. D. A. standards outlined in Iowa Agr. Exp. Sta. Bul. P. 99.

2/ The steers were graded by F. A. Ralston, Extension Animal Husbandman, Montana State College.

experiment those steers fed a ration adequate or borderline in phosphorus with normal calcium content (lots 1 and 2) improved in feeder grade from low good to high good. The steers which received a deficient phosphorus ration (lot 3) showed no change. The lot 4 steers fed a borderline phosphorus ration with excess limestone responded the same as did the phosphorus deficient steers in lot 3. Those animals in lot 5, fed a ration with excessive calcium and deficient phosphorus, became slightly poorer in feeder grade. These data suggest that a phosphorus deficiency may alter body conformation to produce a narrower animal with a shallower body. This effect is accentuated by the presence of excess calcium in the ration. South African workers (Theiler and Green, 1932) reported that the beef breeds did not remain true to type on phosphorus deficient veldt but showed a tendency to "become higher on the front legs, longer of head and croup, narrower of chest, and smaller of heart girth." Figures 19 and 20 show an animal whose body conformation has been altered by phosphorus deficiency. (Compare with the same steer in figure 25)

Table XVII also shows the changes in condition score as a result of the various treatments. Lots 1 and 2 fed adequate or borderline phosphorus with normal calcium in the ration carried the same amount of finish as at the beginning of the trial, whereas the phosphorus deficient steers in lots 3 and 5 changed in condition from average fair to poor plus. The calves fed borderline phosphorus with excess limestone in the ration carried the least finish of any of the lots and showed the greatest decline in condition score. However, when these animals were graded, 3 steers each from lot 3 and lot 5 had received a daily phosphorus drench for 3



Figure 20 Steer 8 Fed Ration 5 Showing Poor Body Conformation Produced by Low Phosphorus and Excess Calcium in the Ration



Figure 21 Steer 8 Fed Ration 5 Showing a Very Typical Stance of a Phosphorus Deficient Steer

weeks, were carrying a large fill, and had gained some in condition. This treatment gave these steers an advantage over those in lot 4.

These data indicate that phosphorus deficient animals carry less finish than normal animals, and that the feeding of excess calcium accentuates this effect of phosphorus deficiency.

Salt Consumption

The salt consumption of the steers on the various treatments is shown in Table XVIII. All lots consumed large amounts of salt. Theiler, Green, and DuToit (1927) concluded that for growing cattle the daily requirements are only 1.5 grams of sodium and 5 grams of chlorine. Stanley (1938) reported an average daily salt consumption per cow of 3 ounces in the winter and slightly less than one ounce in the summer, or a year long average of 1.68 ounces. Knox and Neale (1937) recorded an average daily salt consumption by range cattle in New Mexico varying from 1.06 to 1.21 ounces per head per day. Lantow (1933), also in New Mexico, recorded intakes of salt ranging from 2.89 to 3.64 ounces per head per day. Morrison (1948) recommends a salt allowance of 2.0-2.5 pounds per head per month (1.07 to 1.33 ounces per head per day) for beef cattle.

Thus, these steers consumed about twice the normal amount of salt from the salt box, independent of that contained in the concentrate mixture. This abnormal appetite for salt may indicate an unsuspected mineral imbalance, especially in view of the fact that the control animals ate much larger quantities than did the other lots. The steers fed borderline and deficient phosphorus with normal calcium in the ration ingested an intermediate amount of salt. The steers fed excess limestone ate less salt

TABLE XVIII. EFFECT OF THE EXPERIMENTAL RATIONS ON THE SALT CONSUMPTION OF THE STEERS ON EXPERIMENT 2 (120 Days)

LOTS	I	II	III	IV	V
Salt consumed ad lib, oz./ head/day	1.57	0.96	1.07	0.87	1.03
Salt consumed in ration, oz./head/day ^{1/}	1.40	1.28	1.11	1.10	1.02
Total salt consumed, oz./ head/day	2.97	2.24	2.18	1.97	2.05
Average weight for the period, lbs.	399	365	344	351	343
Total salt consumed, oz./ 1000 lbs. body wt./day	7.44	6.14	6.34	5.61	5.98

^{1/} The concentrate mixture contained 1 percent salt.

than the others. If only the amount consumed from the salt box is considered, these records suggest that phosphorus deficiency decreased the salt consumption and that the excessive limestone fed to lot 4 depressed the salt consumption to the level of the deficient steers in lot 3. This observation implies that mixing phosphorus supplements with salt to induce consumption may be an inefficient practice, especially where phosphorus deficiency is pronounced. The data also indicate that the high calcium of ration 5 reduced the consumption from the salt box below the level of the lot 3 steers.

Photographic Studies

Individual photographs of each steer were made near the beginning of the trial on February 6 and again on May 23, just before the steers were removed from experiment. The pictures were made in the chute shown in figure 6 and described on page 31.

Figures 22 through 26 show representative steers from each lot before and after treatment.

These photographs show some striking differences in the response of the steers to different treatments. The control steers both made substantial increases in length of body. Steer 2 in lot 1 grew 6 inches in length during the period. The animals receiving a restricted phosphorus intake increased in height as much as the controls (about two and one-half inches) but did not make any definite growth in length. This height growth in the deficient animals appears to be due primarily to an increase in the length of the long bones of the leg, thus producing an upstanding animal with a shallow body. The deficient steers are also narrower than the controls as

indicated by the narrow head of steer 8 in lot 5 (figure 26), and substantiated by observation.

The lot 2 steers receiving a borderline level of phosphorus with normal calcium did not grow as much in length as the lot 1 animals and did not have as much bloom. The steers in lot 4 which received a borderline phosphorus ration with excess calcium were shaggier in appearance and lower in condition than the animals in lot 2, but they did not show any outstanding changes in body conformation. The phosphorus deficient steers in lot 3 became more upstanding and shallower of body during the trial, but, the alteration in type was not as extreme as that produced in lot 5 by a ration deficient in phosphorus with an excess of limestone. The only growth detected in these calves was in the length of the long bones of the leg.

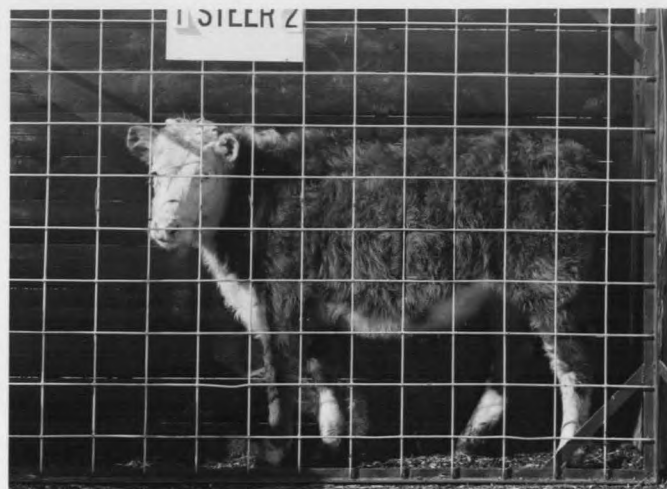
These photographs indicate that phosphorus deficiency restricts growth and in extreme cases confines growth to the leg bone, thus altering the conformation. The pictures also show that rough hair coat and lowered condition is associated with low phosphorus rations. Excess limestone accentuates these effects of phosphorus deficiency.

Figures 27 through 33 show the steers by lots at the conclusion of the trial. The drenched and undrenched steers in lots 3 and 5 are shown separately. The drenched steers appear more alert and show more bloom than the undrenched animals.

Effect of Phosphate Drenching

Representative steers from lots 3 and 5 were drenched with phosphorus daily in order to test the hypothesis that the poor feed consumption of the steers in lots 3, 4, and 5 was due to the unpalatability of their

Figure 22 Representative Steers From Lot I on Experiment 2 Before and After Treatment



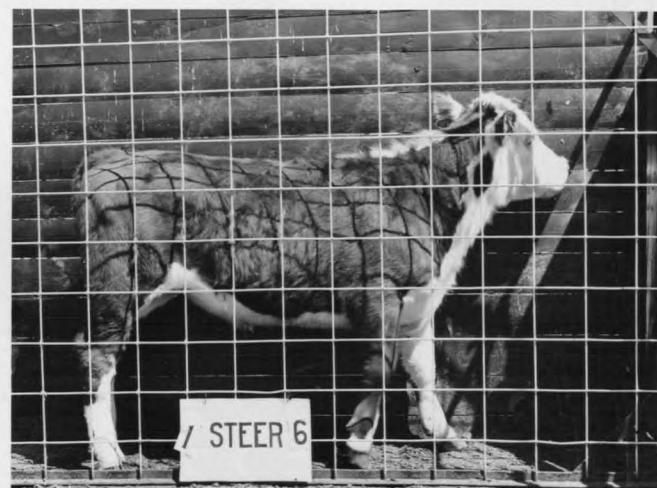
Lot I Steer 2 Feb. 6, 1950



Lot I Steer 2 May 23, 1950



Lot I Steer 6 Feb. 6, 1950

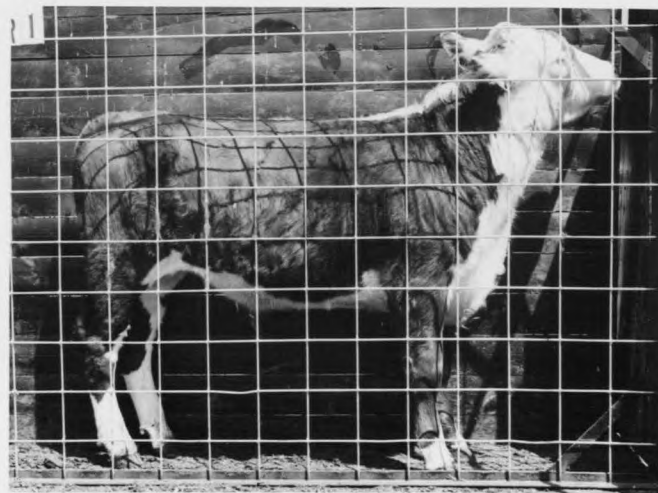


Lot I Steer 6 May 23, 1950

Figure 23 Representative Steers From Lot 2 on
Experiment 2 Before and After Treatment



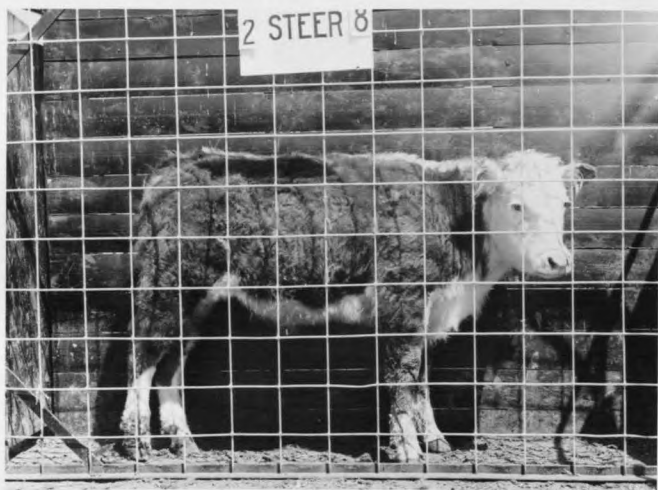
Lot 2 Steer I Feb. 6, 1950



Lot 2 Steer I May 23, 1950



Lot 2 Steer 8 Feb. 6, 1950

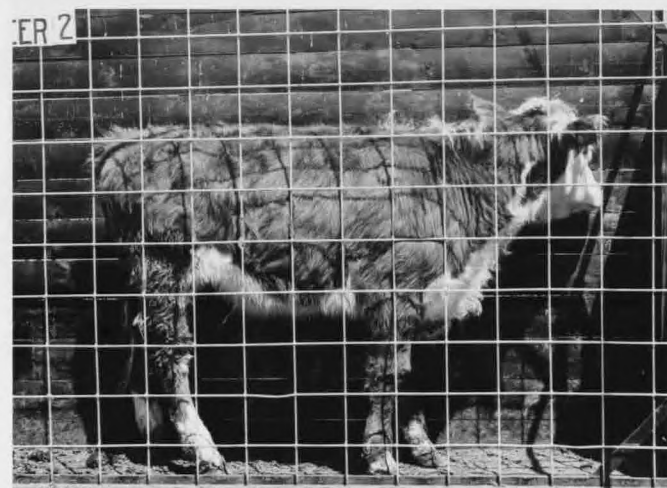


Lot 2 Steer 8 May 23, 1950

Figure 24 Representative Steers From Lot 3 on
Experiment 2 Before and After Treatment



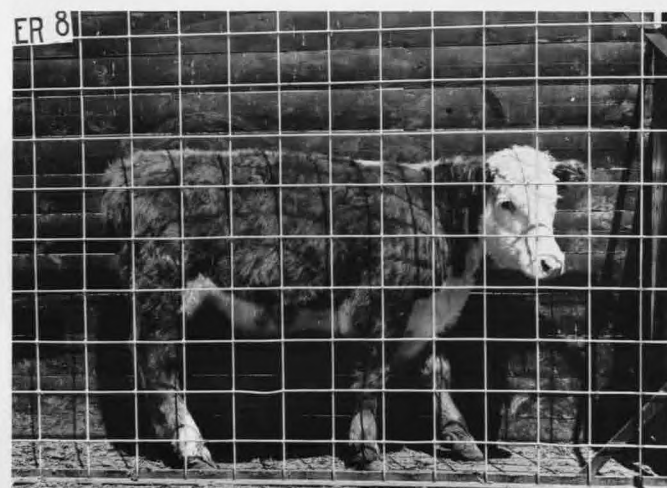
Lot 3 Steer 2 Feb. 6, 1950



Lot 3 Steer 2 May 23, 1950

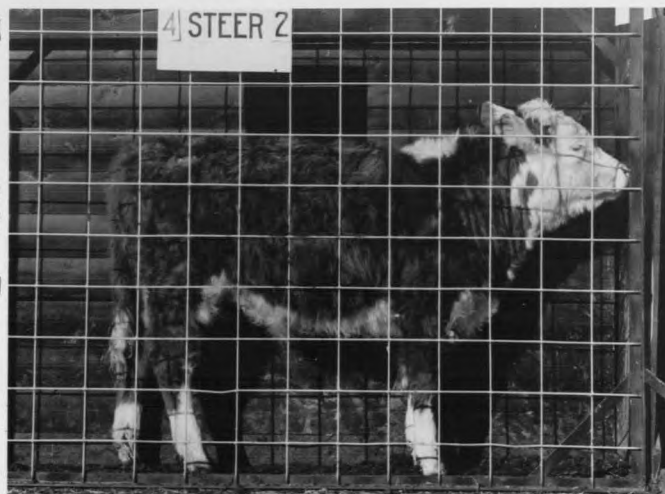


Lot 3 Steer 8 Feb. 6, 1950

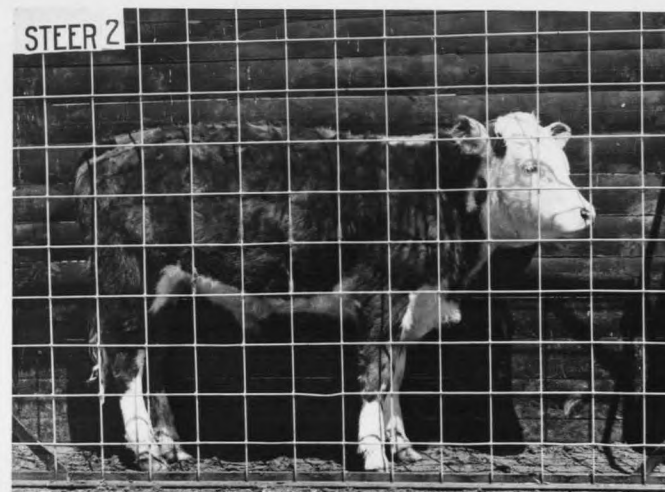


Lot 3 Steer 8 May 23, 1950

Figure 25 Representative Steers From Lot 4 on Experiment 2 Before and After Treatment



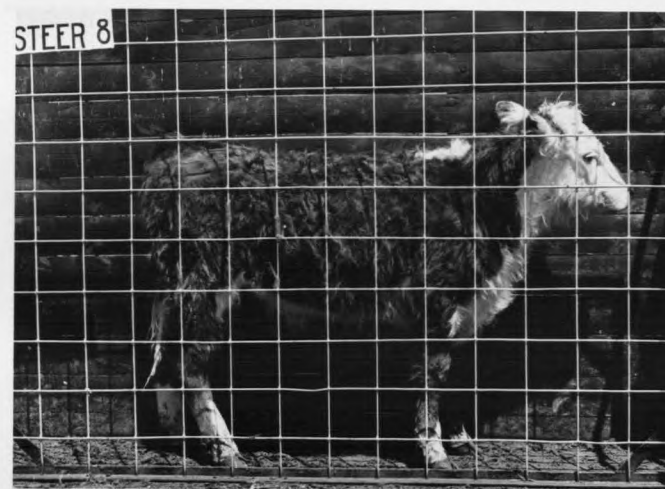
Lot 4 Steer 2 Feb. 6, 1950



Lot 4 Steer 2 May 23, 1950



Lot 4 Steer 8 Feb. 6, 1950

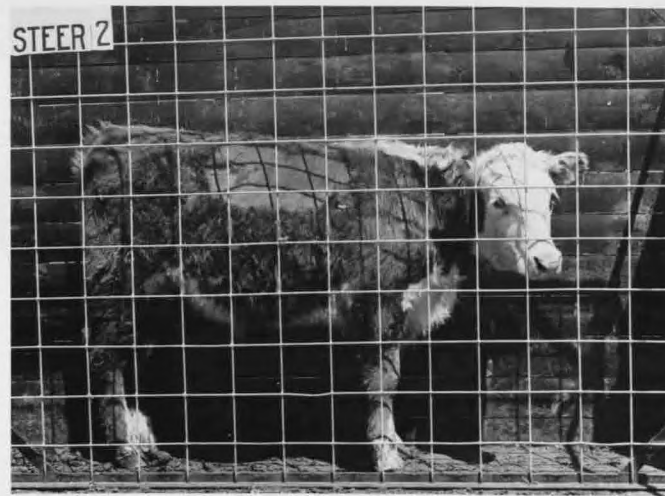


Lot 4 Steer 8 May 23, 1950

Figure 26 Representative Steers From Lot 5 on Experiment 2 Before and After Treatment



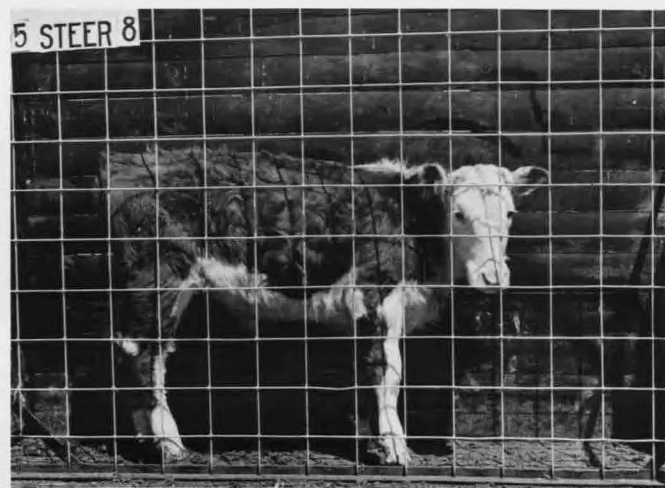
Lot 5 Steer 2 Feb. 6, 1950



Lot 5 Steer 2 May 23, 1950



Lot 5 Steer 8 Feb. 6, 1950



Lot 5 Steer 8 May 23, 1950



*Figure 27 The Steers Fed Ration 1
at the End of Experiment 2*



*Figure 28 The Steers Fed Ration 2 at
the End of Experiment 2*



Figure 29 The Undrenched Steers Fed Ration 3 at the End of Experiment 2



Figure 30 The Drenched Steers Fed Ration 3 at the End of Experiment 2



*Figure 31 The Steers Fed Ration 4
at the End of Experiment 2*



Figure 32 The Undrenched Steers Fed Ration 5 at the End of Experiment 2



Figure 33 The Drenched Steers Fed Ration 5 at the End of Experiment

rations.

On April 28, 3 steers were selected from each of lots 3 and 5 and quartered in the lot 5 pen. The steers from lot 5 were quartered with those remaining in lot 3. All steers were kept on their same previous rations. The 6 steers selected from the two deficient lots were individually given access to carefully measured quantities of monosodium phosphate and salt. Consumption was very irregular. On May 1, the remaining mineral was removed, dried and weighed, and the steers drenched with 118 grams of monosodium phosphate dissolved in water to make one-half pint of solution. This drench provided about 30 grams of phosphorus and was to be given every other day.

Toxic Effect of Overdosage

Within 4 hours after the first drench was administered steer 5 in lot 5 was down with convulsions. Three other steers showed mild incoordination. The entire group was unsteady and stood with their backs arched. Steer 5 was still able to walk when first noticed, but would stumble and fall. In another hour he was unable to rise. The steer grunted and ground his teeth as though in pain, the eyeballs protruded, and when disturbed he threshed about on the ground aimlessly. A blood sample was taken and 200 cc. of a 20 percent calcium gluconate solution which contained no phosphorus was given intravenously. ^{15/} As soon as the entire 200 cc. had been administered, the steer got up with no apparent difficulty and walked away. The animal shook violently from the effect of the calcium

^{15/} Dr. Lee Seghetti of the Veterinary Research Laboratory took the blood sample and made the intravenous injection.

gluconate injection, but no longer showed any signs of incoordination or pain. The tetany did not recur.

The blood analyses showed a plasma calcium and phosphorus level of 8.8 mg. percent and 12.3 mg. percent respectively. Three days previously the plasma levels were 10.8 mg. percent and 2.8 mg. percent for calcium and phosphorus respectively. Although the calcium plasma level was not exceptionally low, the plasma phosphorus was abnormally high, and the relationship of the elements in the blood stream was almost reversed. Shohl (1936) studying the effect of low calcium--high phosphorus diets in the production of rickets and tetany in the rat reported that "Tetany is found associated with low calcium and high phosphorus in the serum. Although such blood values were present in the animals made ricketic on high phosphorus--low calcium diets, they showed only moderate tetany. But the same blood picture is present when animals with low phosphorus rickets or even normals are changed to high phosphorus diets. These animals respond with tetany of such violence as often to be fatal. This is presumably due to the rapid change in the blood from low phosphate to high phosphate with the rapid deposition of calcium phosphate in the bones."

Best and Taylor (1945) stated that the intravenous injection of 0.5 gram per kilogram of body weight of acid phosphate would produce tetany. Steer 5 was drenched with 0.76 grams per kilogram of body weight of sodium acid phosphate. The tetany produced, however, was not due to the lowered calcium plasma level alone because on March 30, the lot 1 steers averaged only 8.3 mg. percent calcium in the plasma.

These data show that excess phosphorus supplied as a drench will

produce tetany in ruminants, that tetany in ruminants may occur with the "readily ionizable calcium" of the plasma as high as 8.8 mg. percent which is barely below the minimum normal value of 9.0 mg. percent according to Dukes (1947). The data also indicate that the peak of absorption of a phosphate drench is from 4 to 6 hours after drenching.

Effect on Performance

After the spectacular effect of the 30 gram phosphorus drench, the steers were drenched daily with 59 grams of monosodium phosphate dissolved in water to make 12 ounces of solution. This drench supplied approximately 15 grams of phosphorus or the full daily requirement of these calves. Two days after the first drench, the steers ate everything which was offered to them and licked the troughs. The feed consumption of the smaller steers doubled in 10 days. By the end of the 28 day weigh period the drenched steers were consuming as much or slightly more than the animals in the control lot.

Table XIX shows the performance of the drenched and the undrenched steers from lots 3 and 5. The drenched steers in lot 3 consumed 16 percent more feed per unit of body weight and gained almost twice as much as the undrenched steers. The drenched steers in lot 5 ate 39 percent more feed and gained nearly 5 times as much as the undrenched. The drenched steers in lots 3 and 5 gained 3.04 and 2.12 pounds per head per day respectively. A portion of this gain was due to fill. Nevertheless, the results indicate that the phosphorus drench improved the appetite, the efficiency of feed utilization, and consequently the weight gains. These results show that phosphorus deficiency and not the palatability of the ration was the limit-

TABLE XIX. EFFECT OF PHOSPHATE DRENCHING ON THE PERFORMANCE OF THE STEERS ON EXPERIMENT 2 IN LOTS 3 AND 5 DURING THE FIFTH WEIGH PERIOD

TREATMENT	Lot 3			Lot 5	
	Undrenched	Drenched ^{1/}		Undrenched	Drenched ^{1/}
Number of steers	4	3	:	4	3
Phosphorus in the ration, %	0.14	0.46	:	0.13	0.45
Calcium in the ration, %	0.41	0.44	:	2.12	2.32
Parts calcium to one part phosphorus	3.03	0.94	:	16.07	5.13
Phosphorus intake-grams/100 lbs. body wt./day	0.94	3.87	:	0.71	4.00
Calcium intake-grams/100 lbs. body wt./day	2.85	3.65	:	11.52	20.52
Initial weight, lbs.	341	403	:	315	396
Feed consumed-lbs./100 lbs. body wt./day	1.54	1.84	:	1.19	1.95
Average daily gain, lbs.	1.08	3.04	:	0.45	2.12
Feed-lbs./100 lbs. gain	506	271	:	956	392
Calcium plasma level, mg. %	12.4	12.2	:	12.8	12.2
Phosphorus plasma level, mg. %	2.8	7.1	:	2.6	7.2
Carotene plasma level, mcg. %	91.7	78.3	:	111.2	68.3

^{1/} These steers were drenched with about 15 grams of phosphorus daily from monosodium phosphate.

ing factor in determining the feed consumption of these steers before drenching.

The plasma calcium was not affected by the drench even though the phosphorus in the plasma increased from about 2.6 mg. percent to over 7 mg. percent. The phosphorus drench did, however, lower the plasma carotene in lots three and five, 15 percent and 39 percent respectively, as compared with the undrenched steers in each lot.

Lignin Digestion Trial

In April 1950 a digestion trial was conducted with lambs to test the hypothesis that the lignin which was used as a filler in the experimental steer rations had no energy value. The rations fed are shown in Table XX. Ration 1 was the same as the ration 1 fed to the steers except that timothy hay made up 30 percent of the total ration rather than 20 percent. Ration 2 was the same as ration 1 except that the lignin was omitted from the concentrate mixture which was consequently fed at the rate of 6 percent less per pound of body weight. Thus, if lignin had no feeding value, the coefficients of apparent digestibility of the dry matter of the two rations would be the same.

Six lambs were fed on each of the two rations during a 20 day preliminary period and a 10 day collection period. The feed intake was standardized at 10.01 grams per pound of body weight. The fecal collection bags were emptied twice daily and a 20 percent aliquot taken and dried in sacks over a steam radiator. The results are given in Table XXI and show that the lignin used as a filler in these steer rations had no effect on the digestibility of these rations as tested with lambs.

TABLE XX. FEED MIXTURES FED IN THE LIGNIN DIGESTION TRIAL WITH LAMBS

RATION 1		:	RATION 2	
Concentrate mixture	Pounds	:	Concentrate mixture	Pounds
Beet Pulp	50.00	:	Beet Pulp	50.00
Wheat Straw	12.25	:	Wheat Straw	12.25
Corn	15.00	:	Corn	15.00
Blood Meal	6.50	:	Blood Meal	6.50
Urea	1.25	:	Urea	1.25
Dextrose	7.50	:	Dextrose	7.50
Salt	1.00	:	Salt	1.00
Monosodium Phosphate	0.50	:	Monosodium Phosphate	0.50
Lignin	6.00	:	Total	94.00
Total	100.00	:		
Roughage	Pounds	:	Roughage	Pounds
Timothy hay	30.00	:	Timothy hay	30.00

TABLE XXI. THE EFFECT OF LIGNIN ON THE APPARENT DIGESTIBILITY OF RATION 1 BY LAMBS

TREAT- MENT	Ration 1 (Contained 6% lignin)				:	Ration 2 (Contained no lignin) ^{1/}			
Lamb No.	Ration Consumed 2/ grams	Feces Voided 2/ grams	Ration Digested 2/ grams	Coefficient of Apparent Digestibility: percent	:	Ration Consumed 2/ grams	Feces Voided 2/ grams	Ration Digested 2/ grams	Coefficient of Apparent Digestibility percent
1	12,360.0	3,275.5	9,034.5	73.5	:	10,297.5	2,725.0	7,572.5	73.5
2	10,570.0	2,840.5	7,729.5	73.2	:	10,196.0	2,676.0	7,520.0	73.8
3	10,680.0	3,002.0	7,678.0	71.9	:	10,619.0	3,010.0	7,609.0	71.7
4	10,570.0	2,812.0	7,758.0	73.4	:	9,663.0	2,730.5	6,932.5	71.7
5	10,350.0	2,564.5	7,785.5	75.3	:	10,086.0	2,625.5	7,460.5	74.0
6	11,010.0	3,021.0	7,989.0	72.6	:	9,874.5	2,635.0	7,239.5	73.3
Total	65,540.0	17,515.5	43,024.5	439.9	:	60,736.0	16,402.0	44,334.0	438.0
Mean				73.3	:				73.0

^{1/} Ration 2 was fed at the rate of 6 percent less per pound of body weight than was ration 1.

^{2/} These figures are air dry weights.

Performance of Steers on Pasture

After the feeding trial was completed the steers were placed on irrigated pasture with free access to a phosphorus supplement and to grain in order to study the effect of the rations fed during the winter on their summer performance.

The steers were removed from the feeding trial on May 26 and were accustomed to a ration of barley, beet pulp, and corn. On June 1 the steers were put out on a 15 acre irrigated pasture seeded to a modified Huntley mixture with free access to a mineral supplement containing 16 percent phosphorus 16/ and to a self feeder containing one-third barley, one-third beet pulp and one-third corn. The only salt supplied for the first 56 days on pasture was the 10 percent contained in the mineral supplement. The salt was so restricted in order to induce greater consumption of phosphorus. The steers were weighed on June 29 and July 27, and are to be continued on grain and grass with mineral supplementation until fall to study the effect of the various rations fed during the winter on the summer performance of these animals. Feed and mineral consumption, 28 day weights, final grade and condition, and selling price will be recorded for each animal and reported elsewhere. The data obtained during the first two weigh periods are recorded in Table XVII.

These results show that the steers which had a high feed consumption and made good weight gains in dry lot gained more slowly during the first period on pasture than did the other steers, partly because the increased 16/ Misco mineral supplied gratis by the Misco Mills division of Centennial Mills, Bozeman, Montana.

TABLE XXII. EFFECT OF THE EXPERIMENTAL RATIONS FED DURING THE WINTER ON WEIGHT GAINS OF THE STEERS ON SUMMER PASTURE

TREATMENT	I	II	III		IV	V	
			Undrenched	Drenched ^{1/}		Undrenched	Drenched ^{1/}
Number of steers ^{2/}	6	8	4	3	8	3	3
Initial weight, lbs.	542	485	385	512	440	399	483
Average daily gain-June, lbs.	1.9	2.2	2.8	2.4	2.5	3.2	2.4
Average daily gain-July, lbs.	3.0	2.7	3.3	2.6	2.9	3.2	3.5
Average daily gain-Period, lbs.	2.4	2.4	3.0	2.5	2.7	3.2	3.0
Mineral supplement consumed ^{3/}	180.25 lbs. (5.8 grams phosphorus per head per day)						
Grain consumed ^{4/}	19,200 lbs. (8.9 lbs. per head per day)						

^{1/} These steers were drenched with about 15 grams of phosphorus from monosodium phosphate daily from May 1 to May 26, 1950.

^{2/} The pasture was stocked with 38 steers during June and 39 in July.

^{3/} 42 lbs. of 15% phosphorus supplement mixed at the Station was fed. The remainder (138.25 lbs.) of the supplement fed was Mixco Mineral (16% phosphorus) furnished by Misco Mills, Bozeman, Montana.

^{4/} Mixture of 1/3 corn, 1/3 barley, 1/3 beet pulp.

fill of the deficient steers was tabulated as gain. The gains of these animals improved during the second period. If gain over both weigh periods of only the undrenched steers is considered, the data indicate that the rate of gain on pasture is inversely proportional to the phosphorus intake during the winter under the conditions of this experiment.

Good consumption of mineral (5.8 grams phosphorus per head per day) and high feed consumption (8.9 lbs. per head per day) were achieved. All lots made excellent gains.

SUMMARY AND CONCLUSIONS

The results of two experiments in which a total of 77 steer calves were individually fed according to appetite for 105 and 120 days respectively on simplified rations containing adequate, borderline, or deficient phosphorus with normal or excess calcium are reported. All rations were supplemented with vitamins A and D and the trace minerals iodine, cobalt, copper, and manganese. The following measurements were made: daily feed consumption, 28-day weight, 28-day plasma calcium and phosphorus, initial and terminal plasma carotene, initial and terminal photographs, and total salt consumption. The effect of drenching phosphorus deficient steers with monosodium phosphate solutions was studied. A digestion trial was conducted with lambs to test the hypothesis that lignin had no feeding value. A grazing experiment was conducted in which the 1950 experimental steers were placed together on irrigated pasture with free access to grain and to phosphorus supplement to study the effect of the winter rations on their summer performance.

The following conclusions seem warranted on the basis of the results obtained in these experiments:

- ①. Under the conditions of these experiments, wood-chewing was not due solely to a phosphorus deficiency, but may have been due to the finely divided state in which the rations were fed.
- ②. The first effect of phosphorus deficiency detected by the measurements used in these experiments was the reduced efficiency of feed utilization which began during the third weigh period, after at least 64 days on the experimental rations.

3. The feed consumed per 100 pounds of body weight was reduced by lack of phosphorus and was further reduced by the addition of excess limestone. The poor feed consumption of the steers fed rations deficient in phosphorus with normal or excessive calcium was not due entirely to the unpalatability of the ration, because when these steers were drenched with phosphorus their feed consumption equalled that of the control steers.
4. In this experiment the feeding of a ration containing a borderline level of phosphorus with normal calcium to steers reduced the average daily gain 24 percent as compared with the controls, without reducing the feed consumption. Phosphorus deficiency reduced the gains 70 percent, however, the feed consumption was also reduced.
5. The feeding of excess limestone with borderline phosphorus in the ration reduced the rate of gain 36 percent as compared with steers fed normal calcium and borderline phosphorus. However, the feeding of excess limestone with a deficient phosphorus ration did not depress the gains any further than a phosphorus deficient ration with normal calcium.
6. The coefficient of correlation between feed consumed per 100 pounds body weight and rate of gain was $+0.640$.
7. After storage had been depleted, the phosphorus plasma levels were related to the phosphorus intake in a general way only and did not necessarily reflect the previous phosphorus nutrition of the animal.

8. The calcium plasma levels were unaffected by the experimental treatments. Raising and lowering of the plasma phosphorus caused no definite corresponding change in the plasma calcium.
9. The carotene plasma levels were inversely proportional to the plasma phosphorus levels and to the phosphorus intake. Excess calcium in the ration was associated with a higher percentage of carotene in the plasma. This association appeared to be independent from the influence of phosphorus deficiency.
10. Prolonged phosphorus deficiency altered the body conformation, apparently by restricting growth of the skeleton primarily to the long bones of the legs, and so produced upstanding animals with shallow bodies. This condition was especially well developed in one steer fed a deficient phosphorus ration with excess calcium. Excess calcium accentuates this effect of phosphorus deficiency.
11. The symptoms of phosphorus deficiency observed in this experiment were: impaired feed utilization, reduction in rate of gain, poor feed consumption, depraved appetite, emaciation, rough hair coat, stiffness of the hind legs, enlargement of the knees and hocks, and alteration of body conformation.
12. A case of phosphate tetany in a steer is described which was induced by drenching with 0.76 grams per kilogram of body weight of monosodium phosphate.
13. The administration of a phosphate drench to phosphorus deficient steers, fed rations deficient in phosphorus with normal and

excess calcium, caused a marked improvement in feed consumption, feed efficiency, weight gains, vigor, and general appearance. The appetite of the anorexic steers responded to the drench within 48 hours.

14. Lignin had no effect on the apparent digestibility of these steer rations as tested with lambs.
15. Steers wintered on phosphorus deficient rations with normal or excessive calcium made excellent gains on summer pasture when properly supplemented.

LITERATURE CITED

- Anonymous. 1949. 151 Questions on Cattle Feeding and Marketing.
Iowa Agr. Exp. Sta. Bul. P. 99.
- Association of Official Agricultural Chemists. 1945. Official and Tentative Methods of Analysis of the Association of Official Agricultural Chemists.
6th Ed. 932 pp. Association of Official Agricultural Chemists, Washington, D. C.
- Bard, E. 1949. The Mineral Nutrient Content of the Annual Parts of Herbaceous Species Growing on Three New York Soil Types Varying in Limestone Content.
Ecology 30:384-389.
- Beeson, W. M., D. W. Bolin, C. W. Hickman, and R. F. Johnson. 1941. The Phosphorus Requirement for Growing and Fattening Beef Steers.
Ida. Agr. Exp. Sta. Bul. 240.
- Best, C. H. and N. B. Taylor. 1945. The Physiological Basis of Medical Practice.
4th Ed. 1169 pp. The Williams and Wilkins Company, Baltimore, Md.
- Boyer, D. D., P. H. Phillips, and J. K. Smith. 1944. The Separation of Carotene From Vitamin A for the Determination of Vitamin A in Blood Plasma.
Jour. Biol. Chem. 152:445-452.
- Burke, E. and H. E. Morris. 1941. Some Causes of Infertility in Montana Soils.
Mont. Agr. Exp. Sta. Cir. 164.
- Clarke, S. E. and E. W. Tisdale. 1945. The Chemical Composition of Native Forage Plants of Southern Alberta and Saskatchewan in Relation to Grazing Practices.
Tech. Bul. 54. Dominion of Canada, Dept. of Agr., Swift Current, Sask.
- Cox, W. M. and M. Imboden. 1936. The Role of Calcium and Phosphorus in Determining Reproductive Success.
Jour. Nutr. 11:147-176.
- Davis, R. E. and L. L. Madsen. 1941. Carotene and Vitamin A in Cattle Blood Plasma with Observations on Reproductive Performance at Restricted Levels of Carotene Intake.
Jour. Nutr. 21:135-146.

- DeLoureiro, J. A. and G. J. Janz. 1944. Iodometric and Colorimetric Methods for the Estimation of Calcium in Serum Based on the Use of an Improved Permanganate Solution. *Biochem. Jour.* 38:16-19.
- Dukes, H. H. 1947. *The Physiology of Domestic Animals*. 6th Ed. 817 pp. Constock Publishing Company, Inc., Ithaca, New York.
- DuToit, P. J., A. I. Malan, and J. W. Groenewald. 1933. Studies in Mineral Metabolism XXVII. The Effect of Two Different Calcium Phosphorus Ratios Upon the Growth of Calves. *Onderstepoort Jour. Vet. Sci. and Anim. Ind.* 1:421-424.
- Eckles, C. H. and T. W. Gullickson. 1933. Phosphorus Deficiency in the Rations of Cattle. *Minn. Agr. Exp. Sta. Tech. Bul.* 91.
- Eveleth, D. F., D. W. Bolin, and A. I. Goldsley. 1949. Experimental Avitaminosis A in Sheep. *Amer. Jour. Vet. Res.* 10:250-255.
- Fairbanks, B. W. 1939. The Calcium-Phosphorus Ratio. *North Amer. Vet.* 20:17-21.
- Fiske, C. H. and Y. Subbarow. 1925. The Colorimetric Determination of Phosphorus. *Jour. Biol. Chem.* 66:375-400.
- Forbes, E. B. and M. H. Keith. 1914. Phosphorus Compounds in Animal Metabolism. *Ohio Agr. Exp. Sta. Tech. Bul.* 5.
- Gaines, P. C. 1948. Commercial Feeds Report for 1948, Part II. *Mont. Agr. Exp. Sta. Bul.* 455.
- Gordon, A. and A. W. Sampson. 1939. Composition of Common California Foothill Plants as a Factor in Range Management. *Calif. Agr. Exp. Sta. Bul.* 627.
- Greenberg, D. M. 1947. The Dynamics of Calcium and Phosphate Metabolism. *U. of Calif. Pub. in Physiology.* 8:277-292
- Guilbert, H. R., G. H. Hart, K. A. Wagnon and H. Goss. 1944. The Importance of Continuous Growth in Beef Cattle. *Calif. Agr. Exp. Sta. Bul.* 683.

- Hart, G. H., H. R. Guilbert, and H. Goss. 1932. Seasonal Changes in the Chemical Composition of Range Forage and Their Relation to Nutrition of Animals.
Calif. Agr. Exp. Sta. Bul. 543.
- Knox, J. H. and E. P. Neale. 1937. Mineral Supplements for Cattle on Phosphorus Deficient Range.
N. Mex. Agr. Exp. Sta. Bul. 249.
- Koch, F. C. 1937. Practical Methods in Biochemistry.
2nd Ed. 290 pp. William Wood and Co., Baltimore, Md.
- Lantow, J. L. 1933. The Assimilation of Calcium and Phosphorus From Different Mineral Compounds and Their Effect on Range Cattle.
N. Mex. Agr. Exp. Sta. Bul. 214.
- Lewis, J. K. and W. H. Burkitt. 1949. Mont. Agr. Exp. Sta. Unpublished Data.
- Mitchel, H. H. 1947. Mineral Requirements of Farm Animals.
Jour. Anim. Sci. 6:365-377.
- Morrison, F. B. 1948. Feeds and Feeding.
21st Ed. 1207 pp. Morrison Publishing Co., Ithaca, New York.
- National Research Council. 1945. Recommended Nutrient Allowances for Beef Cattle. Wash., D. C.
- Payne, G. F. 1950. Mont. Agr. Exp. Sta. Unpublished Data.
- Ross, O. B. and W. D. Gallup. 1949. The Effect of Phosphorus Deficiency on Blood Plasma Carotene (abstract)
Jour. Anim. Sci. 8:628-629.
- Sarvis, J. T. 1941. Grazing Investigations on the Northern Great Plains.
N. Dak. Agr. Exp. Sta. Bul. 308.
- Savage, D. A. and V. G. Heller. 1947. Nutritional Qualities of Range Forage Plants in Relation to Grazing With Beef Cattle on the Southern Plains Experimental Range.
U. S. D. A. Tech. Bul. 943.
- Shohl, A. T. 1936. Rickets in Rats XV. The Effect of Low Calcium-High Phosphorus Diets at Various Levels and Ratios Upon Production of Rickets and Tetany.
Jour. Nutr. 11:275-291.

- Snedecor, G. W. 1946. Statistical Methods.
4th Ed. 485 pp. The Iowa State College Press, Ames, Iowa.
- Stanley, E. B. 1938. Nutritional Studies With Cattle on a Grassland Type
Range in Arizona.
Ariz. Agr. Exp. Sta. Bul. 79.
- Stanley, E. B. and C. W. Hodgson. 1938. Seasonal Changes in the Chemical
Composition of Some Arizona Range Grasses.
Ariz. Agr. Exp. Sta. Tech. Bul. 73.
- Theiler, A., P. J. DuToit, and A. I. Malan. 1937. Studies in Mineral
Metabolism XXXVII. The Influence of Variations in the Dietary
Phosphorus and in the Calcium-Phosphorus Ratio on the Production
of Rickets in Cattle.
Onderstepoort Jour. Vet. Sci. and Anim. Ind. 8:375-414.
- Theiler, A. and H. H. Green. 1932. Aphosphorosis in Ruminants.
Nutr. Abstr. and Reviews 1:359-385.
- Theiler, A., H. H. Green and P. J. DuToit. 1927. Minimum Mineral Require-
ments of Cattle.
Jour. Agr. Sci. 17:291-314.
- Watkins, W. E. 1943. Composition of Range Grasses and Browse at Varying
Stages of Maturity.
N. Mex. Agr. Exp. Sta. Tech. Bul. 311.
- Welch, H. 1924. Bone Chewing by Cattle.
Mont. Agr. Exp. Sta. Cir. 122.
- Welch, H. 1950. Mont. Agr. Exp. Sta. Personal Communication.



N378
L585e, cop. 2 96016
Lewis, J. K.

The effect of excess calcium with borderline & deficient phosphorus.

NAME AND ADDRESS

4125/637 N. Jackson
Ext. 1000 MSU

NOV 28 '65

RT# 3
KENNETH HARTWIG

JUN 25 '74

INTERLIBRARY LOAN

Stillwater Co. Library
Columbus, Mont. - P.O. #

N378
L585e
cop. 2

96016