PART I. PHOSPHORUS REQUIREMENTS OF RANGE BEEF CATTLE

PART II. EFFECTS OF HIGH LEVELS OF MANGANESE SUPPLEMENTATION ON REPRODUCTION AND LACTATION OF BEEF CATTLE AND RABBITS, AND ON THE FECAL EXCRETION OF CALCIUM AND PHOSPHORUS BY STEERS

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Submitted to the Faculty of the Graduate School of
the Oklahoma Agricultural and Mechanical College
in Partial Fulfillment of the Requirements
for the Degree of
DOCTOR OF PHILOSOPHY
1952

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1952

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ACKNOWLEDGMENT

The writer wishes to express his appreciation to Dr. A. B. Nelson, Animal Husbandry Department, for his assistance during the conduct of this study and preparation of the manuscript. Grateful acknowledgment is also extended Dr. W. D. Gallup, Agricultural Chemistry Research Department, for his helpful suggestions and direction of the chemical analyses, and to Dr. A. E. Darlow, Head of the Animal Husbandry Department, for his valuable counsel.

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PART I. PHOSPHORUS REQUIREMENTS OF RANGE BEEF CATTLE

INTRODUCTION

There are extensive areas in the United States and other countries where the soil is known to be deficient in phosphorus. Forage grown in these areas often has a low content of phosphorus, and livestock subsisting on it fail to grow and reproduce normally. Although the soil type is important in maintaining fertility, over-grazing, over-cropping, and erosion have contributed to the mineral impoverishment of the soil.

It has been recognized for many years that phosphorus is an essential dietary constituent. It forms a large proportion of the bony structure and is found in every living cell. Phosphorus is found in the soft tissues in organic combinations such as phosphoprotein, nucleoprotein, phospholipid, and phosphocreatine. Since phosphorus functions in numerous vital processes, there is little wonder that an adequate intake of this element is essential for optimal performance.

It has become a widespread practice to provide livestock, particularly cattle, with a phosphorus supplement. Bonemeal is the supplement ordinarily used, although rock phosphate and dicalcium phosphate are also used to some extent.

The amount of phosphorus required by beef cattle for maintenance and reproduction has not been extensively investigated. A considerable number of experimental studies have been conducted to determine the phosphorus needs of dairy cattle. The minimum and optimum quantities of phosphorus to feed range cattle still remains an unsettled question. The experiment which is reported in the first part of this thesis was initiated to determine how much phosphorus beef cattle need, under range conditions, for maintenance and reproduction.

REVIEW OF LITERATURE

According to Mitchell and McClure, (1937), a phosphorus deficiency has been reported from every continent. In the United States the following states have a recognized phosphorus deficiency: Montana, Florida, Texas, Minnesota, Wisconsin, Michigan, Kansas, Utah and California. Many of the other states have a border-line deficiency.

The typical symptoms of aphosphorosis were produced in experimental cattle by Eckles and associates (1932). Prairie hay containing 0.106 percent phosphorus which was grown on phosphorus-deficient soil was fed to dairy cattle in metabolism stalls for an extended period of time. When a ration providing 0.9 grams of phosphorus per 100 pounds of body weight was fed to growing heifers, there were indications of pica, a decided retardation of growth, listlessness and stiffness. During the second 30-day period the inorganic phosphorus of the plasma dropped to 3.12 mg. percent. For the entire period of 360 days the average value was near 2.5 and dropped to a low point of 1.68 mg. percent during the twelfth 30-day period. Normal calcium values were observed during the entire period. These workers also observed that feeding a ration deficient in phosphorus resulted in depressed milk production and a reduction in the percentage of bone ash in the skeleton.

For many years cattlemen in South Texas observed that some of their cattle became stiff and emaciated, and that reproduction was not normal. In many cases these cattle consumed parts of decayed carcasses and subsequently died as a result of toxins produced by the organism Clostridium botulinum bovis in the dead animal. To study this problem, Black and associates (1943) conducted an experiment on the King Ranch in South Texas. Chemical analyses of grass samples revealed that most of the forage contained less than 0.12 percent phosphorus. Four lots of crossbred cattle, 25 animals per lot, were used in the experiment. Cattle in Lot 1 were fed no mineral supplement, those in Lot 2 were fed a sufficient amount of bonemeal to provide 6.5 grams of phosphorus per day for dry cows and heifers and 14.3 grams of phosphorus per day for lactating cows. Cattle in Lot 3 were fed the same amount of bonemeal as the cows in Lot 2 and were fed trace minerals in addition. The animals were fed the mineral supplement by hand-dosing each day. Feeding the mineral supplement resulted in heavier calves at weaning, a larger calf crop, and a superior condition of the cows. There was no significant difference in weaning weights between calves produced by cows fed the different supplements.

Stanley (1938) did not find it advantageous to feed a mineral supplement to cows which were grazing perennial grasses containing an average of 0.178 per cent phosphorus. Although at times the grasses contained as little as 0.04 percent phosphorus, it appeared that the cattle were able to store adequate phosphorus in times of plenty to supply their requirements during a scarcity. The cows not fed a phosphorus supplement had an average plasma inorganic phosphorus value of 4.97 mg. percent as compared to 5.46, 4.87, and 4.75 mg. percent for the cows receiving cottonseed cake, monosodium phosphate, and monocalcium phosphate, respectively. Apparently there was an adequacy of phosphorus since the cows of all lots produced calves of equal weight and quality.

Knox and associates (1941) conducted an experiment with Hereford cattle to determine the phosphorus requirements of range cattle on native grass pastures of New Mexico. They found that cattle fed dicalcium phosphate over a three-year period produced claves which averaged 429 pounds in weight at weaning as compared to 347 pounds for calves produced by cows not fed a phosphorus supplement. The cows in this experiment had plasma phosphorus levels of less than 4.0 gm. percent much of the time, and occasionally the level was as low as 2.0 mg. of inorganic phosphorus per 100 ml. of plasma. In the winter the values were ordinarily 2.0 to 3.0 mg. percent, while in the summer they were 3.0 to 4.5 mg. percent. The phosphorus content of the herbage consumed by the cows was lowest in February (0.048 percent) and highest in August (0.136 percent).

It has been observed by numerous workers that a deficiency of phosphorus in the ration interferes with feed utilization. Riddell and Hughes (1934) conducted a series of experiments to determine the cause of the reduced efficiency. They found that dairy cows in a condition of aphosphorosis digested their feed as well as the control animals. A chemical examination of the feces and urine revealed that there was no abnormal loss of energy in the excreta of the phosphorus-deficient animals. The outstanding difference between the phosphorus-deficient animals and the controls was the higher energy metabolism of the phosphorus-deficient animals as measured by a portable metabolism apparatus.

Kleiber and associates (1936) conducted an experiment with beef heifers to determine the effect of a phosphorus-deficient ration on growth and efficiency of energy utilization. Two heifers which were fed a ration containing 0.13 percent phosphorus ceased to grow after being fed the ration six months, while the control heifers fed a ration which contained 0.4 percent phosphorus continued to grow. The inorganic phosphorus of the blood from the phosphorus-deficient animals dropped from 9.0 to 3.9 mg. of phosphorus per 100 ml. of blood serum, while the control animals maintained a level of 9.0 mg. percent. It was found that a phosphorus deficiency had no effect on body temperature, digestibility and metabolizability of the food energy, respiratory quotient, and fasting catabolism. It appeared that a phosphorus deficiency lowered the total efficiency of energy utilization mainly by depressing the appetite. "It decreased the partial efficiency of energy utilization, the efficiency of food protein for sparing body protein, and appetite of the animals."

Woodman and Evans (1930) concluded that the mineral matter in coarse hay did not affect its digestibility when fed to yearling wethers. This hay contained 0.21 to 0.28 percent P_2O_5.

Huffman and co-workers (1933) found that 10.0 to 12.0 grams of phosphorus fed daily to dairy cattle from 18 months of age to time of calving furnished adequate phosphorus for maintenance, normal growth, and development of the fetus. Anorexia was the most pronounced symptom of aphosphorosis observed when a smaller amount was fed. The phosphorus requirement for milk production was found to be 0.5 to 0.7 grams of food phosphorus per pound of milk. The maintenance allowance was placed at 10.0 grams daily per 1000 pounds of body weight.

It has been observed by many investigators that cattle fed insufficient phosphorus were subject to various kinds of breeding trouble. In this regard, Theiler (1928) found that 51 percent of the cows fed no phosphorus supplement calved normally, while 80 percent of the cows fed bonemeal calved normally. Reduced mortality and superior development of the calves were also noted. Death losses were high in the cattle which were not fed a phosphorus supplement. At 15 months of age the heaviest calves weighed 700 pounds, which was approximately twice the weight of calves from the cows not receiving phosphorus supplementation.

Guilbert (1930) found that yearling heifers grazing on phosphorus-deficient pastures often failed to breed the second year. Low serum-phosphorus values provided evidence that failure to breed was perhaps due to a deficiency of dietary phosphorus.

Lantow (1932) compared the feeding of phosphorus to cows on the range with an unsupplemented lot. He found that the cows which were fed additional phosphorus matured earlier, produced larger calf crops, had lower death losses when calving as heifers, and produced heavier calves at weaning.

Hart (1928) presented evidence that failure to conceive was often due to a restricted mineral intake. "The disturbed rhythmic functioning of the ovary is one of the most delicate evidences of impaired physiological function due to a lowered plane of nutrition."

Palmer and associates (1941) concluded that a combined deficiency of phosphorus and protein in the bovine ration delays sexual maturity, represses normal evidences of estrum, but does not interfere with normal regularity of ovulation or the ease of conception. "However the marked dystocia (mainly maternal) which occurred in four of the eight animals employed for the breeding study must be regarded as probably due in large measure to the dietary deficiencies imposed."

A rather common method of diagnosing aphosphorosis has been to determine the amount of inorganic phosphorus present in the blood plasma of the animal. A review of the published plasma phosphorus values shows a wide range which may be considered normal.

Black and associates (1943) found that cattle were subject to aphosphorosis when the phosphorus level of the whole blood became less than 4.0 mg. percent. Using plasma phosphorus as the criterion for the determination of phosphorus adequacy, Knox, Benner, and Watkins (1941) observed values of 3 to 4.5 mg. percent during the summer period, and from 2.0 to 3.0 mg. percent during much of the winter period. In spite of these low values, the cows reproduced normally and raised good calves.

Maynard (1947) gives the range of 4.0 to 9.0 mg. of phosphorus per 100 ml. of plasma as normal values, while Dukes (1947) states that the normal range for the bovine is 2.3 to 9.6 mg. percent.

Huffman (1933) and others believe that values under 4.0 mg. percent are indicative of a pending aphosphorosis.

Greaves and associates (1934) analyzed blood from 40 grade yearling steers. At the beginning of the experiment the plasma contained 2.41 to 3.01 mg. of phosphorus per 100 ml. Phosphorus supplements in the form of bonemeal, cottonseed cake, wheat bran, and barley effected an elevation in the plasma phosphorus within 38 days. These values were near 5.0 mg. percent. Bonemeal was the most effective and barley was the least effective. There was a high correlation between the intake of phosphorus and the inorganic phosphorus values of the plasma.

EXPERIMENTAL

Objective

The objective of this experiment was to determine the phosphorus requirements of beef cattle under practical range conditions.

Procedure

This experiment was initiated in 1947. By chemical analyses, a borderline phosphorus deficiency was found in the soils of north central Oklahoma, while soils in southeastern Oklahoma were found to be deficient in phosphorus. An area 10 miles west of Stillwater was selected to represent the north central section of the state, and a section of grassland 2 miles west of Wilburton was selected to represent the southeastern section of Oklahoma. At each area 30 head of bred two-year-old Hereford heifers were divided into three lots of 10 head each. At the beginning of the third year, 12 bred heifers were added to each lot at Stillwater and 10 to each lot at Wilburton.

During the winter period the cattle were confined to small traps and full-fed prairie hay plus approximately 1.25 pounds of corn gluten meal per head daily. The cows of Lot 1 obtained phosphorus only from the feed. The cattle in Lots 2 and 3 were fed in addition enough dicalcium phosphate to provide a total dietary intake of 1.5 and 2.5 grams of phosphorus per 100 pounds of body weight, respectively. The dicalcium phosphate was fed each day with the corn gluten meal.

During the grazing season each lot of cows was maintained in a separate pasture, and the different lots of cows were rotated among the pastures at regular intervals. The bulls were in the pastures with the cows from May 1 to September 1. To eliminate variation in calves due to breeding, the bulls were rotated among the lots of cows. At Stillwater the cows in Lots 1 and 2 were not fed a phosphorus supplement during the grazing season, while those in Lot 3 were fed free-choice, a mixture of two parts salt and one part dicalcium phosphate. At Wilburton the cows of Lot 2 were fed a supplement consisting of 1 part dicalcium phosphate and 9 parts of salt, and Lot 3 cows were fed 1 part dicalcium phosphate and 2 parts salt.

At approximately 56-day intervals throughout the year blood samples were obtained from the jugular vein. Calcium, phosphorus, and carotene determinations were made on the plasma. Weight and reproduction data were obtained on each lot of cattle as the experiment progressed.

Feed Analyses

Samples of the feeds used during the experiment were analyzed for total nutrients, calcium and phosphorus. The results of these analyses are presented in Table I. Corn gluten meal was selected as the protein supplement because it usually has a low content of phosphorus. The meal used in 1950, however, contained twice as much phosphorus as that used in 1947. The prairie hays from the Stillwater and Wilburton areas were essentially equal but relatively low in phosphorus. The prairie hay grown at Stillwater was slightly lower in protein than the hay grown at Wilburton.

Table 1. Chemical composition of feeds and grasses

Feedstuff	Percent dry matter	Percent composition of dry matter						
		Ash	Protein	Fat	Fiber	N.F.E.	Ca	P
Dicalcium phosphate								
11- 5-46	98.57						23.2	18.70
11-20-48	96.52						25.1	18.74
Corn gluten meal								
11- 7-46	92.92	2.42	49.75	1.58	3.49	42.76	0.13	0.38
11-17-47	94.13	2.32	49.00	1.90	3.00	43.78	0.19	0.42
11-20-48	94.71	5.02	43.35	3.18	3.89	44.56	0.24	0.69
11-30-49	94.14	6.47	45.62	3.02	4.95	39.94	0.16	0.73
Prairie hay, Wilburton								
11- 9-46	92.34	6.73	4.22	2.22	32.07	54.76	0.46	0.06
9-28-47	92.68	6.28	5.03	2.44	34.39	51.86	0.41	0.06
11-11-48	93.54	7.16	4.28	2.10	35.01	51.45	0.52	0.05
11- 4-49	94.12	7.55	4.15	3.29	31.24	53.77	0.75	0.05
Prairie hay, Stillwater								
1-16-47	94.51	7.67	3.74	2.65	32.31	53.63	0.45	0.06
10-14-47	92.44	6.74	3.99	2.70	32.37	54.20	0.46	0.06
11-20-48	94.68	7.52	4.43	2.05	32.82	53.18	0.42	0.06
11- 4-49	94.20	7.80	4.95	2.11	34.82	50.32	0.46	0.06
Grass, Stillwater								
5-17-47	93.27	7.75	9.28	3.14	31.27	48.56	0.43	0.12
Grass, Wilburton								
5- 4-47	93.32	5.14	8.23	2.56	30.97	53.10	0.35	0.10
Big Bluestem, Stillwater								
6- 9-48	93.26	6.49	7.87	4.07	31.24	50.33	0.30	0.12
Big Bluestem, Wilburton								
6- 2-48	91.73	5.38	7.28	2.07	32.75	52.52	0.32	0.08
Little Bluestem, Stillwater								
6- 9-48	91.40	7.15	7.71	2.51	31.73	50.91	0.35	0.10
Little Bluestem, Wilburton								
6- 2-48	91.40	6.75	6.84	2.09	32.60	51.72	0.37	0.09
6-19-50	73.52	5.65	4.83	1.51	31.51	56.50	0.32	0.07

RESULTS OBTAINED AT STILLWATER

Plasma Phosphorus Levels

A summary of the inorganic phosphorus values of the plasma is presented in Table 2. During the winter the inorganic phosphorus levels were lowest in the plasma obtained from cattle of Lot 1, the values from cattle of Lot 2 were intermediate, and those from cattle of Lot 3 were the highest. The lots were ranked in this order for each winter bleeding period except one, April 22, 1948. The lowest winter value observed was 2.8 mg. percent, obtained March 18, 1948.

In 1950, the average winter and summer inorganic phosphorus values of the cows in Lot 1 were approximately the same, but for the other three years the phosphorus content of the plasma was higher in the summer than in the winter. The inorganic phosphorus values for cows of Lots 2 and 3, however, were higher in the winter than in the summer. The lowest summer value recorded was 2.9 mg. percent which was observed in cows of Lot 2 on October 10, 1950. In general, the inorganic phosphorus values of the plasma were not low enough for any extended period of time to be considered critical. It appears that the phosphorus supplement fed to Lots 2 and 3 during the winter was effective in maintaining a higher level of inorganic phosphorus than was observed with cows in the control lot.

Weight Data

A summary of the weight data is presented in Table 3. In general the cows in all lots increased in weight from year to year. Ordinarily the cattle

Table 2. Plasma phosphorus levels of cattle at Stillwater (Mg/100 ml)

1947	Feb. 11	Apr. 17	June 2	Oct. 7	Nov. 4		
Lot 1	4.2	6.2	4.1	5.5	3.3		
Lot 2	6.1	7.3	4.2	4.5	5.0		
Lot 3	7.6	8.0	4.2	4.6	6.7		
1948	Feb. 2	Mar. 18	Apr. 22	June 9	Aug. 19	Oct. 27	
Lot 1	3.2	2.8	3.4	4.3	5.1	4.4	
Lot 2	4.4	5.8	6.3	4.7	4.9	5.6	
Lot 3	6.1	5.9	5.4	4.6	5.0	5.5	
1949	Dec. 20	Feb. 15	Apr. 5	June 15	Aug. 11	Sept. 8	Oct. 25
Lot 1	6.0	3.6	3.1	5.0	7.4	4.6	3.6
Lot 2	7.0	5.4	5.2	4.4	6.0	3.9	3.8
Lot 3	7.5	6.7	6.4	4.9	6.4	4.5	3.6
1950	Jan. 9	Mar. 2	Apr. 27	June 28	Aug. 23	Oct. 10	
Lot 1	4.6	3.6	4.5	3.8	4.6	4.5	
Lot 2	5.7	4.9	5.7	4.7	3.1	2.9	
Lot 3	5.1	5.0	6.3	3.6	4.0	4.8	

lost considerable weight (150-203 pounds) during the winter period, but rather large gains (169-278 pounds) were made during the summer period. The average final weights were 1094, 1053, and 1081 for Lots 1, 2, and 3, respectively. The weights obtained at the end of the winter period were subject to large variation since some of the cows had not calved at that time. The weights obtained about February 1 were taken to avoid some of this variation due to calving. The yearly gain of the cows from the various lots did not establish a definite trend. The total gains for the 4-year period were 273, 233, and 261 pounds per cow in Lots 1, 2, and 3, respectively. Apparently the level of dietary phosphorus did not affect the weight of the cows from year to year.

Calf Data

A summary of the calf data is presented in Table 4. In 1947, there was a 100 percent calf crop in all lots with the cows of Lot 2 producing the heaviest

Table 3. Summary of cow weight data, Stillwater

	Lot 1 Low P.	Lot 2 Med. P.	Lot 3 High P.
		1947	
Average Weight per cow (lbs.)			
Jan. 31, 1947	821	820	820
April 21, 1947	655	657	667
Nov. 3, 1947	848	826	857
Gain during winter period	-166	-163	-153
Gain during summer period	193	169	190
Total gain for the year	27	6	37
		1948	
Average Weight per cow (lbs.)			
Nov. 3, 1947	848	826	857
Feb. 10, 1948	875	848	865
April 21, 1948	704	727	722
Oct. 27, 1948	1014	953	1003
Gain during winter period	-134	-99	-135
Gain during summer period	310	236	281
Total gain for the year	166	127	146
		1949	
Average Weight per cow (lbs.)			
Oct. 27, 1948	987	961	991
Feb. 15, 1949	938	924	954
April 15, 1949	812	810	800
Oct. 24, 1949	1021	1001	1014
Gain during winter period	-175	-151	-191
Gain during summer period	209	191	214
Total gain for the year	34	40	23
		1950	
Average Weight per cow (lbs.)			
Oct. 24, 1949	1021	1001	1014
Jan. 31, 1950	1039	998	995
April 20, 1950	816	788	821
Oct. 10, 1950	1094	1053	1081
Gain during winter period	-205	-213	-193
Gain during summer	278	265	260
Total gain for the year	73	52	67

calves. In 1948, the calf crop was 70, 80, and 70 percent for Lots 1, 2, and 3, respectively. The cows of Lot 1 produced calves which were 24 pounds heavier than the calves from Lot 2 but equal in weight with the calves from Lot 3. In 1949, very little difference was observed in the size of the calf crop, but the weaning weights of the calves were 470, 441, and 449 for Lots 1, 2, and 3, respectively. In 1950, the weaning weights were 468 for Lot 1, 442 for Lot 2, and 448 for Lot 3. The above weaning weights were corrected for age of calf, sex of calf, and age of dam. For the 4-year period the average corrected weaning weights were 459, 440, and 443 for calves produced by cows of Lots 1, 2, and 3, respectively. It appears that phosphorus supplementation was not effective in producing heavier calves at weaning time.

Feed Lot Performance of Steers Produced by Cows
Fed Various Amounts of Phosphorus, Stillwater

The cows produced 20 steers in 1947, and 23 steers in 1949. After the steers were weaned, they were placed in the feed-lot and fed a fattening ration consisting of cracked corn, silage, alfalfa hay, and cottonseed meal. The results of the two feeding trials are summarized in Table 5. There was no significant difference between lots in the rate of gain for the 1947-48 period. Steers produced by cows of Lots 1, 2, and 3 gained 1.98, 1.98, and 1.85 pounds per day, respectively. In 1949 the calves from Lot 2 cows gained somewhat slower, but they were considerably smaller when placed on feed. The average daily gain for this feeding period was 2.40 pounds for calves from Lot 1, 2.05 pounds for calves from Lot 2, and 2.28 pounds for calves from Lot 3. These data indicate that the level of phosphorus supplementation of the cows did not affect the subsequent feed-lot performance of the steers.

Table 4. Summary of calf data, Stillwater

	Lot 1 Low Phos.	Lot 2 Med. Phos.	Lot 3 High Phos.
		1947	
Number of cows	10	10	10
Average birth weight of calves	68	73	66
Percent of calf crop weaned	100	100	100
Average weaning weight	350	383	326
Average corrected weaning weight*	435	456	423
		1948	
Number of cows	10	10	10
Average birth weight of calves	67	67	63
Percent of calf crop weaned	70	80	70
Average weaning weight	444	395	435
Average corrected weaning weight*	443	419	444
		1949	
Number of cows	20	20	20
Average birth weight of calves	75	71	73
Percent of calf crop weaned	85	85	83
Average weaning weight	465	417	457
Average corrected weaning weight*	470	441	449
		1950	
Number of cows	21	23	23
Average birth weight of calves	72	71	73
Percent of calf crop weaned	76	91	83
Average weaning weight	501	453	461
Average corrected weaning weight*	468	442	448

* Weights corrected for age, sex, and age of dam.

Table 6 shows the winter consumption of feed for the various lots of cows. Within any given period there was little difference in the consumption of prairie hay which was full-fed to all lots of cows. The amount of hay eaten increased with age and weight of the cows. One of the early symptoms of aphosphorosis is anorexia. These data, however, do not indicate that the intake of hay was stimulated by feeding a phosphorus supplement.

Table 5. Feed-lot performance of steers produced by cows fed various levels of phosphorus, Stillwater

	No. per Lot	Average Weight (lbs) Initial	Final	Average Daily Gain (lbs)
		1947		
Lot 1*	7	359	710	1.98
Lot 2	6	371	723	1.98
Lot 3	7	331	660	1.85
		1949		
Lot 1	12	435	764	2.40
Lot 2	4	300	581	2.05
Lot 3	7	453	766	2.28

* The lot number refers to the lot number of the dam.

Table 6. Feed consumption, Stillwater (Pounds)

	Lot 1	Lot 2	Lot 3
		1947	
Prairie hay	13.96	13.75	13.92
Corn gluten meal	1.38	1.38	1.38
Dicalcium phosphate	___	0.06	0.16
		1948	
Prairie hay	14.51	15.13	14.92
Corn gluten meal	1.22	1.22	1.22
Dicalcium phosphate	___	0.07	0.16
		1949	
Prairie hay	14.44	15.32	15.29
Corn gluten meal	1.09	1.09	1.09
Dicalcium phosphate	___	0.07	0.17
		1950	
Prairie hay	19.38	18.35	18.40
Corn gluten meal	1.25	1.25	1.25
Dicalcium phosphate	___	0.05	0.16

Table 7. Phosphorus supplied by winter ration, Stillwater
(Grams)

	Lot 1	Lot 2	Lot 3
		1947	
Prairie hay	3.92	3.87	3.92
Corn gluten meal	2.40	2.40	2.40
Dicalcium phosphate		5.09	13.58
	6.32	11.36	19.90
		1948	
Prairie hay	3.62	3.42	3.48
Corn gluten meal	2.07	2.07	2.07
Dicalcium phosphate		5.93	13.58
	5.69	11.43	19.13
		1949	
Prairie hay	4.00	4.24	4.24
Corn gluten meal	3.39	3.39	3.39
Dicalcium phosphate		5.95	14.46
	7.39	13.58	22.09
		1950	
Prairie hay	5.64	5.34	5.34
Corn gluten meal	4.16	4.16	4.16
Dicalcium phosphate		4.63	14.04
	9.80	14.13	23.54
4-year average consumption	7.30	12.63	21.16

The amount of phosphorus supplied by the winter ration is shown in Table 7. Of the natural feeds, prairie hay provided approximately 59 percent of the phosphorus intake. The average winter consumption for the 4-year period was 7.30, 12.63, and 21.16, grams of phosphorus for cows of Lots 1, 2, and 3, respectively.

RESULTS OBTAINED AT WILBURTON

Plasma Phosphorus Levels

A summary of the inorganic phosphorus levels of the plasma is presented in Table 8. For the initial bleeding period the average plasma phosphorus values of cows in all lots were the same. In less than three months the cows in Lot 1 had values significantly lower than the others. Subsequently, little difference was observed until December, at which time the values of Lot 1 cows were rather low. During the first year there was a substantial decrease in plasma phosphorus in the fall months, with all average lot values being under 3 mg. percent. During the winters of 1948, 1949, and 1950, the phosphorus values for cows of Lot 1 were quite low, rarely as high as 3 mg. percent. These values tended to be slightly higher during the grazing period. For the cows of Lots 2 and 3, which were fed a phosphorus supplement, the inorganic phosphorus values of the plasma were highest during the winter and lowest during the grazing season. Very little difference was observed between any of the lots during the summer. It should be pointed out that although a phosphorus supplement was provided for the cows of Lots 2 and 3 during the summer, a very small amount was actually consumed. These data indicate that during the winter the phosphorus supplement was effective in maintaining a high level of inorganic phosphorus in the plasma of the supplemented animals. These differences tended to decrease during the summer months. Without phosphorus supplementation the inorganic phosphorus values of the plasma became critically low.

Table 8. Plasma phosphorus levels of cattle at Wilburton (mg/100 ml.)

1947	Feb. 3	Apr. 27	July 27	Aug. 27	Sept. 28	Nov. 24
Lot 1	7.1	4.8	4.5	3.4	2.4	2.5
Lot 2	7.1	6.2	4.5	3.5	2.5	2.1
Lot 3	7.1	6.6	4.1	3.8	2.9	2.6
1948	Dec. 31	Feb. 2	Apr. 16	June 1	Aug. 12	Nov. 1
Lot 1	1.9	1.8	1.8	3.0	3.8	3.3
Lot 2	5.4	5.0	5.3	4.7	4.7	4.3
Lot 3	7.4	5.9	6.5	4.1	4.3	4.7
1949	Jan. 11	Feb. 7	Apr. 19	June 24	Aug. 26	Oct. 31
Lot 1	2.6	2.5	2.8	3.0	3.0	3.0
Lot 2	6.6	6.1	4.9	5.0	3.3	3.0
Lot 3	7.5	6.3	7.7	3.5	3.7	2.7
1950	Jan. 2	Feb. 23	Apr. 27	June 19	Aug. 16	Oct. 16
Lot 1	3.5	2.7	3.1	4.2	3.0	3.6
Lot 2	5.8	5.4	5.6	3.5	3.4	3.1
Lot 3	7.1	6.3	6.0	3.3	3.2	3.8

Weight Data

In general the weight of the cows, as shown in Table 9, increased the first two years of the experiment. Some cows lost weight during the subsequent years. A moderate loss of weight was observed in the winter period during which time most of the cows calved. For the summer period the gains ranged from 65 to 151 pounds, while the winter losses ranged from 12 to 97 pounds. The final weights were 798, 953, and 971 pounds for the cows in Lots 1, 2, and 3, respectively. These data indicate that phosphorus supplementation was effective in the production of heavier mature cows.

Weight data of the cows which weaned calves in 1949 and 1950, are presented in Table 10. At the beginning of the 1948-1949 period, the cows of Lots 2 and 3 were considerably heavier than those of Lot 1, indicating that the phosphorus supplement was effective the first two years of the experiment in producing faster growth. The final weights of the cows which had suckled calves during

Table 9. Summary of cow weight, Wilburton

	Lot 1 Low P.	Lot 2 Med. P.	Lot 3 High P.
		1947	
Average Weight per cow (lbs.)			
Jan. 27, 1947	654	654	654
April 27, 1947	606	605	597
Nov. 22, 1947	693	736	685
Gain during winter period	-48	-49	-57
Gain during summer period	87	131	88
Total gain for the year	39	82	31
		1948	
Average Weight per cow (lbs.)			
Nov. 22, 1947	693	736	685
Jan. 30, 1948	709	770	731
April 16, 1948	625	724	722
Oct. 31, 1948	715	871	873
Gain during winter period	-68	-12	-63
Gain during summer period	90	47	151
Total gain for the year	22	35	88
		1949	
Average Weight per cow (lbs.)			
Oct. 31, 1948	738	860	898
Jan. 30, 1949	709	770	731
April 19, 1949	673	790	791
Oct. 31, 1949	738	898	880
Gain during winter period	-65	-70	-107
Gain during summer period	65	108	89
Total gain for the year	0	38	-18
		1950	
Average Weight per cow (lbs.)			
Oct. 31, 1949	738	898	886
Jan. 30, 1950	798	953	971
April 17, 1950	723	804	789
Oct. 16, 1950	821	893	856
Gain during winter period	-15	-94	-97
Gain during summer period	98	89	67
Total gain during year	83	-5	-30

Table 10. Weight data of cows which weaned calves in 1948-1949, 1949-1950 periods, Wilburton

	Lot 1	Lot 2	Lot 3
Average weight 1/30/47*	648	723	613
	1948-1949		
Average weight 10/31/48	737	854	897
Average weight 10/31/49	648	832	828
Average yearly gain	-89	-22	-69
	1949-1950		
Average weight 10/31/49	806	896	887
Average weight 10/16/50	766	848	834
Average yearly gain	-40	-48	-53

* Average weight of the heifers which subsequently produced calves in 1950. There were 5, 2, and 8 heifers from Lots 1, 2, and 3, respectively.

the summer of 1950 were 766, 848, and 834 pounds for the cows in Lots 1, 2, and 3, respectively. These differences in weight were clearly shown by the superior general appearance of the cows which had been fed the phosphorus supplement. Apparently the high level of phosphorus did not result in greater weight gains than the medium level since at the end of the experiment the cows of Lot 2 weighed 82 pounds more than the cows of Lot 1, and the cows of Lot 3 weighed only 68 pounds more than the cows of Lot 1. Although there was a relatively large loss in weight by the cows of all lots over the two lactating periods in which a comparison was made, a definite trend was not established.

Calf Data

A summary of the calf data is shown in Table 11. With the exception of the first year, the cows of Lot 1 produced the lightest calves. For the first two years the calves produced by cows of Lot 2 were heavier than those of Lot 3; for the third year the weaning weights were about equal, and the Lot 3 calves were the heaviest the fourth year. The percentage calf crop was extremely

Table 11. Summary of calf data, Wilburton

	Lot 1 Low Phos.	Lot 2 Med. Phos.	Lot 3 High Phos.
		1947	
Number of cows	10	10	10
Average birth weight, lbs.	57	55	56
Percent of calf crop weaned	70	50	70
Average weaning weight, lbs.	318	302	305
		1948	
Number of cows	10	10	10
Average birth weight, lbs.	67	68	75
Percent of calf crop weaned	50	20	30
Average weaning weight, lbs.	351	390	369
		1949	
Number of cows	19	13	20
Average birth weight, lbs.	59	69	68
Percent of calf crop weaned	68	69	65
Average weaning weight, lbs.	302	383	388
		1950	
Number of cows	17	13	18
Average birth weight, lbs.	68	76	75
Percent of calf crop weaned	53	77	89
Average weaning weight, lbs.	315	342	356

variable throughout the experiment. In general it was rather low, with the only notable exception being the 89 percent calf crop of cows of Lot 3 in 1950, the fourth year of the experiment. The average weaning weights for the 4-year period were 316, 354, and 359 pounds for calves produced by the cows of Lots 1, 2, and 3, respectively.

In 1948, considerable difficulty was experienced with death losses at time of calving or soon thereafter. A part of the difficulty was traced to an outbreak of Bangs Disease which was observed mainly in Lot 2 cows. Six of these cows reacted to the Bangs test and were slaughtered. In August, 1949, all of the cattle in all lots were vaccinated with Brucella abortus

Table 12. Feed-lot performance of steers produced by cows fed various levels of phosphorus, Wilburton

Lot No.	Number per Lot	Average weight (lbs.) Initial	Final	Average Daily Gain (lbs.)
		1947-1948		
Lot 1	1	274	589	1.76
Lot 2	2	282	574	1.64
Lot 3	4	278	555	1.56
		1949-1950		
Lot 1	3	265	527	1.91
Lot 2	5	377	709	2.42
Lot 3	6	397	727	2.40

strain 19. The heifer calves had been calf-hood vaccinated with this strain when placed on experiment, but were revaccinated.

Feed-lot Performance of Steers Produced by Cows Fed Various Levels of Phosphorus

The cows from all lots produced 7 steer calves in 1947, and 14 steer calves in 1949. In the fall of each respective year these steers were placed on a fattening ration for approximately 180 days. The results are shown in Table 12. The calves in 1947 were rather small. The rate of gain was greatest for the calves from cows which had been fed no phosphorus supplement. The average daily gain was 1.76, 1.64, and 1.56, for Lots 1, 2, and 3, respectively. In 1949, the steers from the cows in Lot 1 weighed considerably less, and the rate of gain was somewhat less than for the steers of the other lots. It appears from these data that the feed-lot performance of steers was not affected by the level of phosphorus supplementation of the dam.

Feed Consumption of Cows at Wilburton

The feed consumption of the cows at Wilburton is shown in Table 13.

Table 13. Daily feed consumption of cows at Wilburton*
(Pounds)

Foodstuff	Lot 1	Lot 2	Lot 3
		1947	
Prairie hay	12.98	13.22	13.14
Corn gluten meal	1.25	1.25	1.25
Dicalcium phosphate	___	.04	0.12
		1948	
Prairie hay	16.00	17.26	17.03
Corn gluten meal	1.23	1.23	1.23
Dicalcium phosphate	___	.05	0.12
		1950	
Prairie hay	16.99	21.81	19.88
Corn gluten meal	1.25	1.25	1.25
Dicalcium phosphate	___	.06	0.16

* Feed records are not complete for 1949 due to loss and sale of part of the experimental animals.

The data for 1949 are omitted because of irregularities due to death losses and disease. Little difference was observed the first two years in the amount of prairie hay which was eaten by cows in the various lots. In 1950, the cows of Lot 1 ate only 16.99 pounds of hay per head daily as compared with 21.81 and 19.80 for cows of Lots 2 and 3, respectively. It may be observed in Table 10, however, that the cows of Lot 1 were lighter in weight than the cows of Lots 2 and 3.

Total Phosphorus Intake

The average amount of dietary phosphorus fed to the cows is shown in Table 14. During the winter period the consumption of phosphorus was 6.83, 11.52, and 18.45 grams of phosphorus per head daily in Lots 1, 2, and 3, respectively. The consumption of the phosphorus supplement during the

Table 14. Phosphorus supplied by winter ration, Wilburton (Grams)

Source	Lot 1	Lot 2	Lot 3
		1947	
Prairie hay	3.53	3.60	3.57
Corn gluten meal	2.18	2.18	2.18
Dicalcium phosphate		3.40	10.18
	5.71	9.18	15.93
		1948	
Prairie hay	4.66	5.02	4.96
Corn gluten meal	2.34	2.34	2.34
Dicalcium phosphate		4.25	10.21
	7.00	11.61	17.51
		1950	
Prairie hay	3.62	4.65	4.22
Corn gluten meal	4.16	4.16	4.16
Dicalcium phosphate		4.97	13.54
	7.78	13.78	21.92
3-year average winter consumption	6.83	11.52	18.45

summer period was extremely low. Cows of Lot 2 consumed less than 5 grams of dicalcium phosphate, while cows of Lot 3 consumed approximately 10 grams per head daily.

Slaughter Data

The experiment at Wilburton was terminated in October, 1950. By rectal examination it was determined that 31 of the 57 cows in the experiment were open. The open cows were sold to a meat packing company at Oklahoma City. When the cows were slaughtered, seven of the livers were condemned. Three of these were from cows of the low-phosphorus lot and four were from cows of the high-phosphorus lot. Nine of the cows had evidences of penetrations of metal into the peritoneal cavity.

In order to obtain data on the composition of the bone, a section of the tibia about three inches from the ankle joint was taken from each animal. The ash content of the bone samples was 68.64, 68.55, and 68.96 percent for cows of Lots 1, 2, and 3, respectively. Apparently the level of phosphorus supplementation did not affect the percentage of bone ash.

Discussion

In general the cattle at Wilburton were unthrifty in appearance and their productivity was sub-optimum as shown by the data which have been presented in the various tables. The cows of all lots were observed to chew bones, wire, and other foreign material. During the summer and fall of 1949, 2 cows from Lot 1 and 1 cow from Lot 2 died. A post mortem examination indicated that death was caused by foreign bodies which had passed through the stomach and had pierced the heart. In each case the reticulum contained several pounds of wire, shotgun shells, tin cans, rocks, nails, and other foreign material.

During the four years of this study the cows of Lot 3 were in noticeably better condition than the cows of Lots 1 and 2, especially during the suckling period. Although some of the cows of Lot 2 became quite thin during the suckling period, in general they were never as thin as the cows of Lot 1.

SUMMARY

Experiments were conducted at Stillwater and Wilburton, Oklahoma, to determine the phosphorus requirements of range beef cattle. At each location 30 head of bred two-year-old grade Hereford heifers were divided into three lots. At the beginning of the third year approximately 10 bred heifers were added to each lot. During the winter period the cows were fed prairie hay and corn gluten meal. The cows in Lot 1 were fed only the phosphorus in the natural feed, and cows of Lots 2 and 3 were fed enough dicalcium phosphate during the winter period to provide a total daily dietary intake of 1.5 and 2.5 grams of phosphorus per hundred pounds of body weight, respectively. During the grazing period the cows grazed native grass pastures. Cows of Lot 1 were fed salt free-choice, and those of Lots 2 and 3 were fed a salt dicalcium phosphate mixture.

Stillwater

1. During the winter period 7.3, 12.6, and 21.2 grams of phosphorus per head daily were fed to the cows of Lots 1, 2, and 3, respectively. The inorganic phosphorus values of the plasma indicated that the cows obtained adequate phosphorus from the natural feeds to prevent aphosphorosis during both the wintering and grazing periods.

2. The reproductive performance of cows in all lots was satisfactory over the four-year experimental period. No breeding trouble was observed which could be attributed to a phosphorus deficiency. The cows of Lot 1

produced calves which were slightly heavier at weaning than the calves from the cows of the other lots.

3. The amount of phosphorus consumed during the winter period did not affect the yearly weight of the cows.

4. It appears, therefore, that under the system of management followed in this experiment, a winter intake of 7.3 grams of phosphorus per head daily was adequate for satisfactory maintenance and reproduction of beef cattle.

Wilburton

1. During the winter period 6.83, 11.5, and 18.5 grams of phosphorus per head daily were fed to the cows of Lots 1, 2, and 3, respectively. The plasma phosphorus levels of cows in Lot 1 became critically low during the late winter months. Inorganic phosphorus values between 2.0 and 3.0 mg. percent were not uncommon at this time. During the winter period the cows receiving a phosphorus supplement had plasma phosphorus levels considerably higher than the cows which were not fed a phosphorus supplement.

2. The cows which were fed a phosphorus supplement were considerably heavier at the end of the four-year period.

3. In general, the reproductive performance of cows in all lots was considered sub-optimum. A small calf crop was produced, and the calves from all lots of cows were light in weight when weaned. The calves from cows receiving a phosphorus supplement, however, were heavier than those produced by unsupplemented cows. The reproductive performance of the cows fed medium and high levels of phosphorus were approximately equal.

4. These data indicate that under the system of management of this experiment an intake of 6.83 grams of phosphorus per head daily during the

winter months was not adequate for maximum reproductive performance of cows in the Wilburton area. The medium level of phosphorus supplementation (a daily dietary intake of 1.5 grams per hundred pounds of body weight) apparently met the phosphorus requirement of the cows.

5. Since satisfactory reproduction was not obtained when a medium or a high level of phosphorus was fed, it apprars that some factor other than a simple phosphorus deficiency interfered with the reproductive performance of the cows.

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PART II. EFFECTS OF HIGH LEVELS OF MANGANESE SUPPLEMENTATION ON REPRODUCTION AND LACTATION OF BEEF CATTLE AND RABBITS, AND ON THE FECAL EXCRETION OF CALCIUM AND PHOSPHORUS BY STEERS

INTRODUCTION

An experiment was conducted at Wilburton, Oklahoma, to determine the phosphorus requirements of range beef cattle. The data strongly indicated that there was some dietary factor(s) adversely affecting the reproduction and lactation of the cows. The poor reproductive performance became more obvious when the Wilburton experiment was compared with a similar experiment conducted during the same period at Stillwater, Oklahoma.

Other than climatic differences, the primary differences between the two experiments were that the cattle at Wilburton weighed somewhat less when the project was initiated and were fed prairie hay grown in the vicinity of Wilburton. The cattle at Stillwater were fed prairie hay from the Stillwater vicinity. During the winter period both groups of cattle were full-fed prairie hay and 1.25 pounds of corn gluten meal per head daily. Each group was grazed in its respective area.

When the data obtained at Stillwater were compared with those obtained at Wilburton, it was observed that the cows at Stillwater made much larger gains during the summer and subsequently lost much more weight during the winter period. The cows at Stillwater produced a higher percentage of calves and at weaning time they weighed an average of 91 pounds more than the calves produced at Wilburton. During the grazing season, the inorganic phosphorus content of the plasma of the Stillwater cows was much higher than that of the Wilburton cows.

Three experiments were conducted at Wilburton, Oklahoma, to determine the value of feeding a trace mineral mixture to weanling and yearling Hereford heifers. On the basis of these experiments it was concluded that it was not beneficial to feed a trace mineral mixture. (For details see Review of Literature).

The prairie hays grown in the Wilburton and Stillwater areas were found to have the following chemical composition, expressed as percentages:

	Ca	P	Si	Fe	Mn	Mg	K	Na	Al
Wilburton Hay	0.524	.053	4.04	.0095	.0253	.516	.450	.144	.0152
Stillwater Hay	0.422	.061	5.63	.0091	.0075	.159	.688	.161	.0148

It may be observed that the hay grown at Wilburton contained much more manganese and magnesium than the prairie hay grown at Stillwater. Only small differences were found in the other mineral constituents. Further analyses (Tidwell, 1951) showed that the hays produced near Wilburton contained from 150 to 270 ppm. of manganese, while the hay produced in the vicinity of Stillwater contained 25 to 75 ppm. of manganese.

Numerous investigators have found that a high level of manganese in the ration of various animals is detrimental, while others have reported evidence to the contrary.

The investigation reported herein was conducted to determine how the feeding of high levels of manganese may affect:

(1) Reproduction of range cows

(2) Certain blood constituents of range cows

(3) Weights of cows

(4) Fecal excretion of phosphorus by steers

(5) Reproduction of rabbits

(6) Growth of weanling rabbits.

REVIEW OF LITERATURE

It was shown that manganese is an essential constituent of the animal diet by Waddell (1930) and by Orent and McCollum (1932). These workers reported that rats fed a diet deficient in manganese grew normally, but that their hair coats became rough after approximately eight months. The males had testicular degeneration, and the females failed to suckle their young properly. In an effort to determine the reason for the high mortality rate of milk-fed rats, Daniels (1934) fed rats low-manganese diets and observed congenital debility, apparently the result of too little manganese in the diet of the mother. Amdur (1945) observed that the length, density, breaking strength, and phosphatase content of the bones of rats receiving a diet deficient in manganese were less than the control group receiving sufficient manganese. Smith and associates (1944) showed that a manganese deficiency produced severe bone malformation in rabbits.

From a practical standpoint, the poultry requirement for manganese is more critical than the requirement of other classes of livestock. Several workers have shown that the abnormal condition in chicks referred to as "slipped tendon" can be prevented by providing adequate manganese in the diet. In this regard, Norris (1938) found that the length of the tibiae of day-old chicks which were produced by hens fed a low-manganese diet were 12.5 to 13.1 percent shorter than those of chicks produced by hens which were fed a high manganese diet. The long bones of the legs were also shorter at three weeks of age. Caskey (1939) fed chicks a ration deficient in manganese and found that they developed bone structures significantly shorter than the control chicks. It was concluded that the abnormal shortening of the bones was a direct result of an upset in the calcium and phosphorus metabolism produced by a manganese-deficient diet.

Grummer and associates (1950) fed four lots of pigs a basal ration consisting of corn, soybean oil meal, corn gluten meal, ground alfalfa, salt, and limestone. The basal ration, which contained 12 to 13 ppm. of manganese, was supplemented with three levels of manganese, 40, 80, and 160 ppm. The pigs fed 40 ppm. of manganese ranked highest in rate and efficiency of gain in each of the four trials. The ration containing 80 ppm. produced slightly faster gains than the basal ration, while the ration containing 160 ppm. produced gains which were approximately equal to the basal. When sows were fed rations containing 40, 80, and 160 ppm. of manganese, fertility was improved but it did not improve their lactating ability.

Johnson (1944), on the other hand, raised pigs which made a satisfactory growth on 7 to 10 ppm. of manganese. Miller and co-workers (1940) attributed a lameness found in pigs to a manganese-deficient ration. Keith (1942) found that the addition of manganese to a low-manganese ration helped to prevent but did not cure lameness in pigs.

Lardy (1942) reported that bull calves fed rations deficient in manganese were unable to produce good quality semen. In some cases an improvement was obtained with injections of vitamin C and manganese.

It appears, therefore, that a small amount of manganese is an essential dietary constituent. Large amounts, on the other hand, may be detrimental. Chornock (1941) fed rats a series of rations containing various amounts of manganese, phosphorus, and calcium. When the rats were fed a rachitogenic diet plus manganese, she found that growth was retarded in proportion to the manganese content of the ration. There was a slight depression of growth with as little as 100 ppm. The addition of potassium citrate produced a striking improvement in calcium and phosphorus retention.

Grummer (1950) conducted an experiment to determine the possible in-hibition of growth when a high level of manganese is fed to pigs. He fed one lot of pigs a basal ration, and another the basal plus 500 ppm. of man-ganese. The pigs on the basal ration gained 1.21 pounds daily as compared to 0.97 pound for the pigs fed the basal ration plus 500 ppm. of manganese. The additional manganese retarded appetite and growth, especially during the latter part of the trial.

Monier-Williams (1949) reported that grass containing 540 to 1320 ppm. Mn was thought to be associated with lactation tetany.

Reid (1947) conducted an experiment in which dairy cows were fed rations containing various amounts of manganese, calcium, and trace elements. Sup-plementation of the basal ration with manganese sulfate in addition to cal-cium carbonate resulted in negative calcium balances in every case. No appre-ciable effect on phosphorus metabolism was observed.

When dogs were fed large amounts of manganese, Von Oettinger (1935) reported that it caused vomiting, gastritis and paralysis.

Holtkamp and Hill (1950) observed that the optimum intake of manganese was 2 mg. per rat daily at 30 days of age and about 3.71 mg. per rat daily at 50 days of age. Rats fed 40 mg. of manganese daily failed to grow as rapidly as those fed only 5 mg. daily.

Nelson and associates (1929) observed that when 100 ppm. of manganese sulfate was added to a basal diet of casein, dextrin, and salts, growth of rats was stimulated. When 600 ppm. of manganese sulfate was added, growth was retarded.

A report by Russell (1944) indicates that hay with a high content of manganese may contain a reduced amount of thiamine. He stated that Carlstrom and Hjarre had produced symptoms of "forage anemia" by feeding hay which was high in manganese and also by feeding a ration low in thiamine. Feeding 50-100 grams of yeast daily to horses which were fed "affected" hay prevented the appearance of the symptoms commonly observed.

"Manganese rickets" were produced by Blumberg and associates (1938) by adding 2.9 percent manganese carbonate to a stock diet of optimal calcium and phosphorus content. These workers concluded that manganese, in manganous compounds easily soluble in the gastric juice, is capable of producing rickets. The manganous ion forms an insoluble phosphate complex.

Skinner and Peterson (1929) fed rats various levels of manganese. It was found that the female rats on a high manganese intake (basal ration plus 5 mg. of manganese per rat daily) were unable to properly nourish their young after rearing several litters. When copper and iron were added to a ration for growing rats, it was observed that "decreases in storage of the element resulting from the addition (1) of copper, (2) of iron and (3) of a combination of the two to the manganese-milk ration were 27, 20, and 26 percent, respectively."

There are some experimental data which indicate that manganese at high levels is not detrimental. Skinner (1931) fed female rats 10 mg. of manganese per day above that in the stock ration. These females were as successful in rearing their young as the females receiving the stock ration only. When $MnSO_4 \cdot H_2O$ equivalent to 2,000 ppm. was added to the ration for a period of 12 weeks, no retardation of growth was observed.

Carratala and Carbonischi (1937) fed rabbits 0.7 to 0.9 mg. of manganous sulfate and 0.1 to 0.94 mg. of manganous chloride per head daily over a period of three weeks. The livers of the treated rabbits were partially degenerated and bone changes were observed.

Blakemore and associates (1937) were of the opinion that grasses particularly rich in manganese would possibly lower the blood magnesium, thus contributing to lactation tetany of cows and sheep.

Becker and McCollum (1938) conducted an experiment with rats to determine the toxicity of manganese chloride. Manganese levels from 499 to 9980 ppm. were added to a stock ration containing 0.63 percent calcium and 0.72 percent phosphorus. Growth was retarded only at the highest level of manganese supplementation. Reproduction, however, was excellent on the high manganese diet. "Evidently the high level of phosphorus effectively prevented symptoms of toxicity by reducing the amount of absorbable manganese."

There may be some relationship between manganese intake and thyroid activity. Ray and Deysach (1942) in their experiments with guinea pigs found that excess manganese was stored in the thyroid gland out of all proportion to that stored by the other organs. As the storage of manganese increased in the thyroid, oxygen consumption became progressively less. Reineke and Turner (1945) showed that the formation of thyroxine is catalyzed by a series of manganese compounds.

Greenberg (1940) used radioactive manganese and administered it both orally and intraperitonially to rats. He found that over 95 percent of the labeled manganese was excreted in the feces, while very little was found in the urine. The absorbed manganese was found principally in the liver, bone, muscle, and blood.

An investigation was conducted by Perla and Sandberg (1939) to determine the matabolic interdependence of Vitamin B_1 and manganese. These workers observed that the toxic effects produced by giving 400 gamma of thiamine parenterally could be alleviated by providing 2 mg. of manganese as $MnCl_2$ per rat daily. Rats fed 2 mg. of manganese in addition to the stock ration showed a disturbance in lactation and maternal instinct, which could be completely counteracted by feeding thiamine.

In another report Perla (1939) stated that a high level of thiamine in rat rations was found to be toxic and that this toxicity could be alleviated by supplementing the ration with manganese. "It was reasoned that perhaps manganese was essential as an oxidative catalyst in the utilization of vitamin B_1 by the animal." Perla, Sandberg, and Holly (1939) found that normal rats on a stock diet stored a greater part of an unusually high manganese ration when it was supplemented with additional thiamine.

Weswig and co-workers (1946) fed rats a diet containing 40 percent bracken fern. This particular fern was obtained from an area in which "fern poisoning" had been observed in cattle. After ten days the rats lost weight rapidly and death occurred approximately 20 days later. The symptoms were strongly suggestive of a thiamine deficiency. When a large quantity of thiamine was fed, the rats recovered with remarkable promptness. No decrease in the toxicity of the air-dried fern was observed when it was heated at 105 degrees centigrade in air for 18 hours.

Numerous experiments have demonstrated that various metals other than manganese affect the utilization of phosphorus.

Street (1942) fed rats a purified diet containing various levels of phosphorus, aluminum sulfate, and aluminum hydroxide. He found that when a soluble form of aluminum, such as aluminum sulfate, was fed to rats in an amount equal to the phosphorus content of the ration (equimolar), there was almost complete precipitation of phosphorus in the intestinal tract. This conclusion was based on growth rates and inorganic phosphorus values of the plasma. Aluminum sulfate was more effective in precipitating the phosphorus than aluminum hydroxide.

Using Steenbock's rachitogenic ration 2965, Branion and associates (1931) replaced the calcium carbonate with an equivalent amount of beryllium carbonate. Rats fed this ration exhibited bone lesions which were similar to rickets and had extremely low inorganic phosphorus values in the plasma. These values were usually below 1.3, and in a few cases were as low as 0.5 mg. of phosphorus per 100 ml. of plasma.

Cox and associates (1931) fed guinea pigs a ration containing soluble aluminum salts in excess of the total phosphorus of the diet. This resulted in a marked lowering of the inorganic phosphorus of the plasma to as low as 15 percent of the normal value. In a period of 12 weeks the ash, calcium, and phosphorus of the bones were reduced to 70 percent of the normal values. Ferric salts produced similar but less drastic results. Feeding mono-sodium phosphate equivalent to the aluminum or iron content prevented the detrimental effects. It was suggested that these effects were due to the precipitation of alimentary phosphorus as the ferric and aluminum phosphates. The phosphorus content of the diet was equivalent to 1350 ppm. of aluminum and 2800 ppm. of iron.

Since numerous reports have been made that certain areas in the United States are deficient in copper, iron, cobalt, or various combinations of these, Nelson and associates (1951) conducted an experiment at Wilburton, Oklahoma, to determine if a deficiency of one of the minor elements existed in that area. In the first trial one lot of grade Hereford heifers was fed a winter basal ration of prairie hay, corn gluten meal, and a phosphorus supplement. Another lot was fed the basal ration plus a trace mineral mixture which provided iron, cobalt, iodine, manganese, and copper. In the second and third trials manganese was omitted from the mineral mixtures. During the grazing period the same heifers were fed the trace minerals in salt. In general, the heifers which were fed the trace mineral mixture gained less than those which were not fed the trace mineral mixture. No differences were observed in the general appearance and thriftiness of the heifers at the end of the summer period.

Apparently the amount of manganese which a plant can obtain from the soil is related to the acidity of the soil. Gooden and Grimmett (1928) reported that drainage conditions have a marked effect on the manganese content of the plant. Lack of drainage increased the content of manganese in the oat plant as much as six times. It was found that the application of chalk definitely depressed the manganese content of the forage.

The amount of manganese found in a species of grass depends to some extent on the ability of that species to take up and store the manganese. Bolin (1934) analyzed several species of grasses which were grown at Caldwell, Idaho. He found that the average manganese content (dry basis) ranged from 78 ppm. for Kentucky bluegrass, to 207.5 ppm. for orchard grass. Alfalfa contained an average of 46.6 ppm. of manganese.

Skinner and Peterson (1928) analyzed various feeds to determine the manganese content and obtained the following values, expressed as parts per million:

Alfalfa hay	72.0
Corn, yellow	5.3
Cottonseed meal	20.0
Oat straw	87.0
Sugar beet roots	200.0
Blue grass	59.0
Timothy hay	32.0
Vetch hay	106.0
Wheat	54.5

EXPERIMENTS

Experiment 1. The Effect of Various Levels of Manganese Supplementation on the Reproductive Performance of Beef Cows

Procedure

Sixty-four grade Hereford cows were divided into four lots on the basis of age and previous reproductive performance. During the winter period the cows were confined to small traps located approximately 10 miles west of Stillwater, Oklahoma. The winter ration for the control lot (Lot 1) consisted of prairie hay, full-fed, 1.4 pounds of corn gluten meal, and salt, free-choice. The cows of Lots 2 and 3 were fed the basal ration plus enough manganese sulfate (Tecmangam*, a feeding grade of manganese sulfate) to provide a total dietary intake of 250 and 500 ppm. of manganese, respectively. The cows of Lot 4 were fed the same ration as the cows of Lot 3, plus enough ferric sulfate and copper sulfate to provide 40 mg. of iron and 4 mg. of copper per 100 pounds of body weight per day. The minerals were mixed with the corn gluten meal and fed in a trough.

The cows in all lots grazed native grass pastures during the summer months. At the beginning of the summer period, the mineral supplement was mixed with salt and placed in covered mineral feeders. The consumption, however, was only approximately one-half the desired amount. Consequently, after July 21, the minerals were mixed with corn. Each cow, including those on the basal ration, was fed one pound of corn daily.

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* Supplied through the courtesy of Tennessee Eastman Corp., Kingsport, Tenn. It contained 65 percent manganese sulfate, 9.5 percent ammonium sulfate and 23 percent magnesium sulfate.

Bulls were placed with the cows May 1, and removed September 1. They were rotated among the lots of cows to eliminate differences due to heredity and breeding efficiency.

Samples of blood for laboratory analysis were taken from the juglar vein at approximately six-week intervals.

Individual cow weights were obtained at the time that blood samples were taken.

Results and Discussion

The chemical analyses of the feeds and grasses are presented in Table 1.

A summary of the production data is shown in Table 2. It may be observed that the cows of all lots lost a great amount of weight during the first winter period. These losses were 218, 240, 235, and 251 pounds per cow for Lots 1, 2, 3, and 4, respectively. The losses for the winter period up to February 1 (weights taken just prior to calving) were 13, 16, 28, and 27 pounds for Lots 1, 2, 3, and 4, respectively. The cows of Lot 1 lost slightly less weight than the cows of the other lots over the entire winter period. For the second winter period the gains up to February 1 were 32, 38, 23, and 27 pounds per cow for Lots 1, 2, 3, and 4, respectively. The average yearly gain was 39 pounds for the cows of Lot 1 and 16 pounds for those of Lot 3, while the cows of Lot 2 lost 8 pounds and those of Lot 4 lost 27 pounds.

The birth weights of the calves were practically the same in all lots. Each experimental lot weaned one or two more calves than the control lot, but this difference did not appear to be due to the mineral supplementation. The weaning weights of the calves when corrected for age and sex, were 452,

Table 1. Chemical composition of feeds and grasses

Feedstuff	Percent dry matter	Percent Composition of Dry Matter						
		Ash	Protein	Fat	Fiber	N.F.E.	Ca	P
Prairie hay								
1950-1951	92.93	7.44	4.91	2.02	35.22	50.41	0.32	0.080
1951-1952	93.59	8.33	4.13	2.25	34.04	44.84	0.38	0.078
Corn gluten meal								
1950-1951	94.44	3.30	48.31	1.10	3.99	43.30	0.11	0.56
1951-1952[1]	93.19	3.29	43.19	1.50	3.93	41.28	0.14	0.58
1952[2]	91.34	2.43	44.52	1.16	3.33	39.90	0.12	0.39
Steamed bonemeal	97.30	90.57					33.14	15.11
Native grass[3]								
May		6.08	9.32	2.04	30.47	52.09	0.25	0.13
July		6.62	5.74	2.54	33.66	51.44	0.31	0.08
September		5.76	4.24	2.34	36.46	51.20	0.27	0.06

[1] Corn gluten meal fed from November to January.

[2] Corn gluten meal fed from January until the end of the winter period.

[3] Average, by species, of four predominant grasses: little bluestem, big bluestem, switch, and Indian.

Table 2. Summary of production data

	Lot 1	Lot 2 250 ppm	Lot 3 500 ppm	Lot 4 500 ppm Mn Plus Fe & Cu
		1950-1951		
Number of cows per lot	16	16	16	16
Average weight of cows (lbs.)				
Initial 10-31-50	1075	1058	1066	1071
Prior to calving 2-1-51	1062	1042	1038	1044
End of winter feeding 5-1-51	857	818	831	820
Final 10-25-51	1114	1050	1082	1044
Winter loss up to calving	13	16	28	27
Total winter loss	218	240	235	251
Summer gain	257	232	251	224
Yearly gain or loss	39	-8	16	-27
Birth weight of calves (lbs.)	78	78	77	78
Number of calves weaned	13	15	15	16
Weaning weight of calves 10-3-51 (lbs.) (corrected for age and sex)	452	463	466	463
		1951-1952		
Number of cows per lot	16	16	15	15
Average weight of cows (lbs.)				
Initial 10-25-51	1114	1050	1068	1051
Prior to calving 1-30-52	1146	1088	1091	1078
Winter gain up to calving	32	38	23	27
Birth weight of calves (lbs.)	78.5	71.9	79.0	75.5

463, 466, and 463 for Lots 1, 2, 3, and 4, respectively. Apparently supplementing the dams with manganese did not depress the weaning weights of the calves.

During the first year the average plasma phosphorus values were approximately the same in all lots. At no time did there appear to be a phosphorus deficiency until January and March of the second winter. In March the inorganic phosphorus values of the plasma were 3.45, 2.96, 2.42, and 2.94 mg. percent for Lots 1, 2, 3, and 4, respectively. Starting in January, 1952, a new supply of

Table 3. Blood constituents of cows
(November, 1950-March, 1952)

	Nov.	Jan.	Feb.	Mar.	May	June	Aug.	Sept.	Oct.	Dec.	Jan.	Mar.
					Phosphorus (mg. per 100 ml. plasma)							
Lot 1	4.38	3.62	3.64	4.13	3.28	4.32	4.49	3.86	3.69	3.64	3.03	3.45
Lot 2	4.68	3.76	3.21	3.69	3.50	4.64	4.91	3.17	3.42	3.30	3.12	2.96
Lot 3	4.84	4.76	3.35	4.04	3.83	5.21	5.02	3.52	3.60	3.41	3.72	2.42
Lot 4	4.00	4.71	3.58	3.38	2.67	4.96	5.00	3.81	4.81	4.14	2.78	2.94
					Hemoglobin (gm. per 100 ml.)							
Lot 1	11.5	10.8	10.9	11.6	11.1	10.8	11.8	11.8	12.1	11.5	11.4	11.3
Lot 2	10.7	10.6	10.6	11.0	10.5	10.7	12.0	11.6	11.6	10.8	11.0	11.3
Lot 3	10.4	10.1	10.2	10.9	9.6	10.1	12.0	11.4	11.1	10.0	10.8	11.0
Lot 4	10.9	11.3	11.0	11.1	10.5	10.5	11.7	11.7	11.4	10.0	10.9	11.8
					Hematocrit (vol. percent)							
Lot 1	38	33	34	36	33	35	34	38	38			
Lot 2	34	31	32	33	31	32	35	39	37			
Lot 3	33	31	31	33	29	31	34	33	36			
Lot 4	35	34	33	33	32	32	35	38	36			
					Plasma Protein (gm. per 100 ml.)							
Lot 1	8.7	8.4	8.5	8.4	8.4	9.0	8.8	8.3	9.0			
Lot 2	8.2	7.9	7.5	8.4	8.4	8.7	8.5	8.0	8.6			
Lot 3	8.4	8.2	7.7	7.8	7.9	8.5	8.6	8.4	8.9			
Lot 4	8.1	8.4	7.9	8.0	8.2	8.8	8.6	8.4	8.5			

corn gluten meal with a phosphorus content of 0.39 (as compared with 0.56 and 0.58 for the previous supplies) was fed. The phosphorus values of the cows of Lot 1, however, remained steady, but the values for the cows of the other lots decreased appreciably. If the manganese combined with the phosphorus of the ingesta to form an insoluble phosphate complex, the loss of phosphorus by way of the feces was not reflected in the phosphorus level of the plasma until possibly the second winter period.

The hemoglobin, hematocrit, and plasma protein values were remarkably uniform among all lots of cows. Apparently manganese supplementation did not affect these values.

Experiment 2. The Effects of High Levels of Manganese on Reproduction and Growth of Rabbits

The rabbit was used as the experimental animal in pilot experiments which might contribute data that would be helpful in planning further experiments pertaining to the cattle production problem observed at Wilburton, Oklahoma. All of the rabbit rations, therefore, were compounded with a high proportion of prairie hay. Corn gluten meal was used as the source of protein in order to keep the phosphorus content of the ration at a moderate level. The ingredients of the rations, including the mineral supplements, were finely ground, thoroughly mixed, and pelleted at a local feed concern.

The rabbit hutches were located in a large room with ample ventilation. The floors of the hutches were made of one-half inch mesh hardware cloth. Each doe was provided with a space 24" x 36". In the growth experiments five or six young rabbits were kept in a space of the same size.

In all the trials the rations were fed in self-feeders. Feed consumption was determined weekly, with the crumbled pellets being weighed back

Table 4. Summary of reproduction data, Trial 1

	Lot 1 Low Mn	Lot 2 High Mn
Number of does	4	3
Average doe loss, grams	346	777
Average litter size at birth	9.6	8.3
Average birth weight, grams	53	46
Average weaning weight, grams	1137	882

and discarded at that time. Ample fresh water was provided each day.

Trial 1. Reproduction

Ten mature New Zealand does were evenly divided into two lots. The does of Lot 1 were fed a basal ration consisting of prairie hay, 65, corn gluten meal, 20, ground wheat, 5, ground oats, 5, and alfalfa meal, 5 percent. In addition 1/6 pound of salt and 15 grams of Delsterol (commercial source of Vitamin D) were mixed with each one hundred pounds of the pellet. The does of Lot 2 were fed the basal ration plus 1,000 ppm. manganese, supplied as manganese sulfate.

If there were more than 7 rabbits in the litter at 7 days of age, the litter was standardized to 7 per litter. Birth weights, weaning weights, and weight changes of the does were obtained as the experiment progressed.

Reproduction data for Trial 1 is presented in Table 4. Four does of Lot 1 and three does of Lot 2 weaned litters. The rabbits fed the basal ration produced young which were heavier at birth, and weighed an average of 255 grams more when weaned. The four does of Lot 1 weaned 22 rabbits, while the 3 does of Lot 2 weaned only 14 rabbits. The does of Lot 1 lost 346 grams each during the trial and those of Lot 2 lost 777 grams. Apparently the number of young weaned, the weaning weights, and the doe weights were impaired by adding 1000 ppm. of manganese to the ration.

Trial 2. Reproduction

Ten weanling New Zealand doe rabbits approximately 2.5 months of age were divided into two lots. For the first 2 months the rabbits of Lot 1 were fed a ration consisting of prairie hay, 40, corn gluten meal, 30, ground wheat, 10, ground oats, 10, and alfalfa meal, 10 percent, plus 1/6 pound salt and 20 grams of Delsterol per hundred pounds of the pellet. The does of Lot 2 were fed the basal ration plus 2000 ppm. manganese. These replacement does were fed each respective ration until they were 4.5 months of age. At this time the does of Lot 1 were changed to a basal ration consisting of prairie hay, 56.5, alfalfa meal, 6.6, ground wheat, 8.3, corn gluten meal, 21.2, and ground oats, 6.6 percent, plus 1/6 pound salt and 15 grams Delsterol per hundred pounds of the mixture. The does of Lot 2 were changed to the new basal ration to which was added 1000 ppm. of manganese. These pellets were used for the duration of the reproduction trial.

A summary of the growth and reproduction data is shown in Table 5. The does which were fed the basal ration gained more rapidly and at breeding age weighed 269 grams more than the rabbits which were fed additional manganese. Three does in each lot were bred. The does of Lot 1 produced young which were heavier at birth and slightly heavier at weaning than the young of Lot 2. The most definite difference between the two lots was in the efficiency with which the does raised their young. Many of the young rabbits in the Lot 2 litters became grossly emaciated and subsequently died. One hundred percent of the young were weaned by the does of Lot 1, as compared with 39 percent for the does of Lot 2. During the reproduction period the does of Lot 1 gained 409 grams, and the does of Lot 2 gained 138 grams. Apparently the high level of manganese in the diet retarded the

Table 5. Summary of reproduction data, Trial 2

	Lot 1 Low Mn	Lot 2 High Mn
Number of does	3	3
Average doe weight when bred (grams)	2932	2560
Average doe weight when litter was weaned (grams)	3341	2698
Average doe gain (grams)	409	138
Average birth weight of young (grams)	58	51
Average weight of young at 60 days of age (grams)	934	899
Total number of young born	19	18
Total number weaned	19	7
Phosphorus values of plasma of does at end of experiment (mg. per 100 ml.)	4.35	4.93

growth rate of the does, both during the growing period and the reproduction period. Manganese also appeared to depress the birth weights, number of young weaned per litter, and the weight of the young at weaning. At the termination of the experiment the inorganic phosphorus values of the plasma were 4.35 mg. percent for does of Lot 1, and 4.93 mg. percent for does of Lot 2.

Trial 3. Growth

Twenty weanling New Zealand rabbits were divided into two lots. The rabbits of Lot 1 were fed a basal pellet consisting of prairie hay, 40, corn gluten meal, 30, ground oats, 10, ground wheat, 10 and alfalfa meal, 10 percent. One-sixth pound of salt and 20 grams of Delsterol were added to each hundred pounds of the mixture. The rabbits of Lot 2 were fed the basal pellet plus 2000 ppm. manganese. Weekly weights and feed consumption data were obtained during the 60-day growing period.

The average total gain was 1035 and 851 for the rabbits of Lots 1 and 2, respectively. The amount of feed consumed was practically the same for both lots. It appears, therefore, that the manganese in the pellet retarded the

Table 6. Composition of the pellets used in Trial 4 (Pounds)

Ingredient	Lot 1	Lot 2	Lot 3	Lot 4
Prairie hay	40	40	40	40
Corn gluten meal	30	30	25	30
Ground oats	10	10	10	10
Ground wheat	10	10	10	10
Alfalfa meal	10	10	10	10
Manganese (as manganese sulfate) ppm.		2000	2000	2000
Brewers' yeast			5	
Bonemeal				4

rate of growth and depressed the efficiency of feed utilization.

When the experiment was terminated, the blood plasma of 5 rabbits from each lot was analyzed to determine the content of inorganic phosphorus. The average value for the rabbits of Lot 1 was 5.85 mg. percent as compared with 5.74 mg. percent for the rabbits of Lot 2.

Trial 4. Growth

Twenty weanling rabbits were equally divided into four lots and fed a growing pellet for 49 days. The composition of the rations fed is shown in Table 6. Weight and feed consumption data were obtained at weekly intervals.

The results of Trial 4 are shown in Table 7. The rabbits which were fed the pellet containing 2000 ppm. of manganese plus 5 percent brewers' yeast (Lot 3) made the most rapid rate of gain. Those which were fed a similar pellet containing 2000 ppm. maganese minus the brewers' yeast gained 267 grams less per rabbit than those of Lot 3. Apparently supplementing the ration with yeast completely neutralized the growth retarding effect of 2000 ppm. of manganese since the rabbits fed yeast gained considerably more weight than the rabbits fed the control ration. This is in agreement with Perla (1939) who found that thiamine counteracted the disturbance caused by feeding

Table 7. Growth and feed data for Trial 4
(Grams)

	Lot 1 Basal	Lot 2 2000 ppm Mn	Lot 3 2000 ppm Mn plus yeast	Lot 4 2000 ppm Mn plus bonemeal
Average weight				
Initial	1215	1293	1138	1186
Final	2539	2444	2556	2433
Average total gain	1324	1151	1418	1247
Average daily feed consumption	136.2	136.7	146.9	138.1

a large amount of manganese to rats.

The rabbits which were fed the high-manganese ration plus bonemeal (Lot 4) grew more rapidly than those not fed bonemeal (Lot 2). Similar results were obtained in an experiment by Becker and McCollum (1938) in which they found that a high level of phosphorus fed to rats on a diet high in manganese effectively prevented symptoms of toxicity by reducing the amount of absorbable manganese.

The rabbits of Lots 1, 2, and 4 consumed approximately the same quantity of feed while those which were fed the pellet containing brewers' yeast (Lot 4) consumed slightly more.

Experiment 3. The Effect of High Levels of Manganese on the Fecal Excretion of Calcium and Phosphorus by Steers

Several investigators have suggested that manganese may combine with the phosphorus of the ingesta and form an insoluble manganese-phosphate complex (Blumberg, 1938; Becker, 1938; Chornock, 1942). Reid (1947) observed large and continuous losses of calcium when dairy cattle were fed mineral supplements containing both manganese and calcium.

Results of the preceding rabbit experiment failed to show a depression

Table 8. Body measurements of steers
(Inches)

Steer	Height at Withers	Heart-girth	Point of shoulder to pinbones
1	45	60	51
2	42	59	47
3	44.5	60	50
4	42.5	58	48
5	45	60	52
6	44.5	59	49

of the inorganic phosphorus values of the blood plasma of either growing or lactating rabbits which were fed a large amount of manganese. It did appear, however, that the high manganese intake depressed birth and weaning weights, and that the growth rate was retarded. In the growth trials the efficiency of feed utilization also appeared to be depressed when the high-manganese rations were fed. Furthermore, as reported in Experiment 1, cattle subsisting on hay with a relatively high content of manganese were observed to have lower inorganic phosphorus values than those fed a low-manganese hay.

This experiment was conducted with steers, therefore, to determine the effect of a high dietary level of manganese on the fecal excretion of calcium and phosphorus.

Procedure

Six grade Hereford steers were used as the experimental animals. At the beginning of the experiment the three smaller steers weighed approximately 435, and the larger steers weighed approximately 500 pounds each. To more accurately determine the size of the animals, measurements were taken of the height at the withers, heartgirth, and the distance between the pinbones and point of the shoulder. The measurements of the steers (obtained at the end of the experiment) are shown in Table 8.

The basal ration fed to the steers is shown in Table 9. The steers were divided into pairs (one large and one small steer) and each pair was fed one of the following rations: (1) basal, (2) basal plus 12 grams of $MnSO_4 \cdot H_2O$ (1000 ppm. Mn), and (3) basal plus 24 grams of $MnSO_4 \cdot H_2O$ (2000 ppm. Mn).

The steers were fed and watered each day at 7:00 A. M. and 5:00 P. M. At each feeding time the weeds and coarse stems were carefully removed from the hay.

The feces was collected twice daily and placed in covered containers. Once each day 5-percent aliquots of the feces were put in glass jars with a pinch of thymol crystals. The jars were sealed tightly and stored under refrigeration until analyzed.

Each trial consisted of a preliminary period of 15 or more days and three 5-day collection periods. At the beginning of the second trial the rations previously fed were switched to a different pair of steers.

At the beginning of each trial a supply of feed adequate for the entire trial was obtained. The cottonseed meal (41 percent protein grade) was thoroughly mixed and placed in metal containers. The yellow corn was coarsely cracked, thoroughly mixed, and stored in metal barrels. A representative sample of each feedstuff was obtained for chemical analyses. The hay samples were obtained by taking a portion at each feeding time.

In order to follow the trend of the inorganic phosphorus of the blood plasma, a sample of blood was taken from the jugular vein at various intervals.

Results and Discussion

The chemical composition of the hay and other supplements fed to the steers is shown in Table 9.

Table 9. Daily amount and chemical composition of hay and other supplements offered steers in Trial 1

Feed	Daily Allowance	Dry Matter	Percentage composition of dry matter						
			Protein (N x 6.25)	Ether Extract	Crude Fiber	N-free Extract	Organic Matter	Ca	P
	Grams	Percent							
Prairie hay	1589	94.26	4.93	2.21	33.74	52.20	93.08	.38	.06
Ground yellow corn	1600	87.76	9.94	5.26	2.44	80.51	98.15	.02	.40
Cottonseed meal	680	93.47	42.86	7.32	12.44	30.64	93.76	.25	1.24
Salt	24								

Table 10. Average daily intake and fecal excretion of phosphorus, calcium, and manganese

Ration	Average daily intake			Average daily fecal excretion								
	Ca	P	Mn	1st 5 days			2nd 5 days			3rd 5 days		
				Ca	P	Mn	Ca	P	Mn	Ca	P	Mn
	Average daily intake											
	gm.	gm.	mg.	gm.	gm.	mg.	gm.	gm.	mg.	gm.	gm.	mg.
Basal												
Steer 1	7.56	14.41	142	4.70	7.17	141	*	6.58	*	3.20	5.94	153
Steer 2	7.56	14.41	142	4.11	5.24	119	3.61	4.81	133	3.26	4.62	188
Basal plus 1000 ppm.												
Steer 3	7.56	14.41	4041	6.65	6.77	3652	6.26	7.47	3657	5.75	6.57	3653
Steer 4	7.56	14.41	4041	6.72	9.95	3896	5.79	9.95	3341	*	9.06	3466
Basal plus 2000 ppm.												
Steer 5	7.56	14.41	7940	6.14	7.41	*	5.84	7.75	6470	5.78	8.51	7292
Steer 6	7.56	14.41	7940	6.14	9.33	6735	6.31	9.41	6265	6.74	9.81	*

* Analyses incomplete.

The daily intake and fecal excretion of calcium, phosphorus, and manganese is presented in Table 10. Each steer had a daily intake of 7.56 grams of calcium and 14.41 grams of phosphorus. In each 5-day collection period the larger steers (numbers 3 and 5) excreted less phosphorus in the feces than the smaller steers (numbers 4 and 6) when the animals were fed supplemental manganese. On the other hand, the larger steer fed the basal ration (number 1) excreted more phosphorus in the feces than the smaller steer (number 2).

As summarized in Table 11, the steers fed the basal ration excreted 3.78 grams of calcium, while the steers fed 12 and 24 grams of manganese sulfate excreted 6.23 and 6.16 grams of calcium daily, respectively. Likewise, the steers fed the basal ration excreted 5.73 grams of phosphorus in the feces daily as compared to 8.30 and 8.70 grams for steers fed 12 and 24 grams of manganese sulfate, respectively. The fecal manganese was roughly proportional to the amount of supplemental manganese fed.

It is clearly indicated that the steers fed both levels of added manganese voided in the feces a very large proportion of the dietary calcium and a substantial proportion of the phosphorus. The steers fed the basal ration voided 50 percent of the calcium and 39.8 percent of the phosphorus; those fed 1000 ppm. of manganese voided 82.4 percent of the calcium and 57.6 percent of the phosphorus; while those fed 2000 ppm. of manganese voided 81.5 percent of the calcium and 60.4 percent of the phosphorus.

In the second 15-day collection period the steers were changed to a different one of the three rations; otherwise the experiment was conducted in the same manner as in the first period. The data were in agreement with those of the first period in that the daily quantity of fecal phosphorus was 6.13, 8.27, and 8.30 grams per steer for those fed the basal ration,

Table 11. Summary of values for fecal excretion of phosphorus, calcium, and manganese

Ration	Fecal Excretion			Difference between intake and fecal output		
	Ca	P	Mn	Ca	P	Mn
	gm.	gm.	mg.	gm.	gm.	mg.
Basal	3.78	5.73	147	3.78	8.68	-5
Basal plus 1000 ppm. Mn	6.23	8.30	3610	1.33	6.11	431
Basal plus 2000 ppm. Mn	6.16	8.70	6690	1.40	5.71	1250

Table 12. Inorganic phosphorus content of the blood plasma of steers (Mg./100 ml.)

Ration	Jan. 7	Jan. 12	Jan. 22	Feb. 3	Feb. 14	Feb. 28
Basal						
Steer 1	8.60	8.20	7.56	6.92	6.80	7.84
Steer 2	8.24	8.04	6.04	8.04	6.72	7.48
Basal plus 1000 ppm. Mn						
Steer 3	8.00	6.28	7.48	8.76	8.52	8.16
Steer 4	7.16	6.84	7.12	7.28	7.12	7.40
Basal plus 2000 ppm. Mn						
Steer 5	7.12	7.36	6.92	6.68	6.88	6.80
Steer 6	7.76	8.88	7.92	7.64	6.84	7.56

basal ration plus 12 grams of manganese sulfate, and basal ration plus 24 grams of manganese sulfate, respectively.

As shown in Table 12, no definite trend was established in the inorganic phosphorus values of the blood plasma. Perhaps a longer period of time is required before the phosphorus content of the plasma reflects the true status of the phosphorus nutrition of the animal. It is also possible that, in spite of the large fecal loss of phosphorus, an adequate amount of phosphorus was available to maintain the inorganic phosphorus level of the plasma.

It appears probable that dietary manganese forms an insoluble manganese-phosphate complex in the gastro-intestinal tract and thereby increases the fecal excretion of calcium and phosphorus. When high-manganese rations are fed, therefore, a dietary level of calcium and phosphorus adequate to compensate for the increased fecal loss, is indicated.

It is recognized that the data supporting this hypothesis are limited and that broad statements are not warranted. If the hypothesis that dietary manganese depresses the absorption of phosphorus is correct, however, it may provide an explanation for the abnormally low inorganic phosphorus values of the blood plasma of the experimental cattle at Wilburton, Oklahoma.

SUMMARY

Experiment 1

Four lots of Hereford cows, 16 per lot, were fed the following winter rations: (1) basal ration consisting of prairie hay, corn gluten meal, and salt; (2) basal ration with the manganese content raised to 250 ppm. with manganese sulfate; (3) basal ration with the manganese content raised to 500 ppm. with manganese sulfate; (4) same as (3) plus 40 mg. iron and 4 mg. of copper per cow daily. During the summer period the cows were grazed on native grass pastures and fed the mineral supplement in the salt or with one pound of corn per cow daily.

The cows fed the basal ration lost somewhat less weight than the cows of the other lots during the first winter period, and gained slightly more the second winter period. The yearly gain was 39, -8, 16, and -27 pounds for the cows of lots 1, 2, 3, and 4, respectively. Only small differences were observed among the birth and weaning weights of the calves. Except for the latter part of the second winter period, the inorganic phosphorus content of the plasma was approximately the same in all lots. The hemoglobin, hematocrit, and plasma protein values were remarkably uniform among all lots.

Experiment 2

Reproduction

Two trials were conducted with New Zealand does to determine the effect of high levels of manganese on reproduction and lactation of rabbits. The does were self-fed the following rations: (1) basal ration consisting of prairie hay, corn gluten meal, ground wheat, ground oats, alfalfa meal, Delsterol, and salt; (2) basal ration plus 1000 ppm. of manganese, supplied as manganese sulfate.

In both trials the manganese appeared to depress the birth weights and the weaning weights of the young. During the suckling periods a much higher mortality rate among the litters of the high-manganese lots was observed. The does which were fed the pellets with a high content of manganese lost considerably more weight in Trial 1 and gained somewhat less weight in Trial 2. Apparently the manganese impaired the reproduction and lactation of the does.

Growth

Weanling New Zealand rabbits were used in two trials to determine the effect of a high level of dietary manganese on the growth rate and feed efficiency of growing rabbits. The basal pellet consisted of prairie hay, corn gluten meal, ground wheat, ground oats, alfalfa meal, Delsterol, and salt.

When 2000 ppm. of manganese was added to the basal pellet, growth was retarded in each trial. The impaired growth rate was partially counteracted with bonemeal supplementation, and completely counteracted with the addition of brewers' yeast to the ration.

Experiment 3

Six grade Hereford steers were placed in digestion stalls and fed the following rations: (1) basal ration consisting of prairie hay, 1589, cracked yellow corn, 1600, cottonseed meal, 680, and salt, 24 grams; (2) basal plus 12 grams of manganese sulfate; (3) basal plus 24 grams of manganese sulfate.

The basal ration provided an intake of 7.56 grams of calcium and 14.41 grams of phosphorus.

No changes in the inorganic phosphorus content of the blood plasma were attributed to manganese supplementation.

The steers fed ration (1) voided 2.78 grams or 50 percent of the dietary calcium and 5.73 grams or 39.8 percent of the dietary phosphorus in the feces; those fed ration (2) voided 6.23 grams or 82.4 percent of the calcium and 8.30 grams or 57.6 percent of the dietary phosphorus; while the steers fed ration (3) voided 6.16 grams or 81.5 percent of the calcium and 8.70 grams or 60.4 percent of the dietary phosphorus in the feces. Apparently manganese supplementation caused large fecal losses of calcium and phosphorus.

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THESIS TITLE: I. PHOSPHORUS REQUIREMENTS OF RANGE BEEF CATTLE

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