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COMPARISON OF METHODS OF SUPPLYING PHOSPHORUS TO RANGE CATTLE
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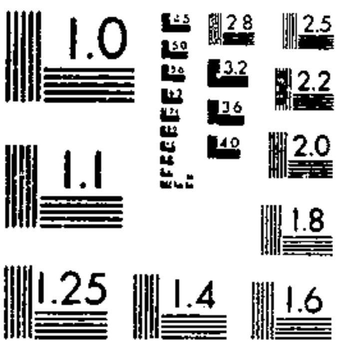

MICROCOPY RESOLUTION TEST CHART
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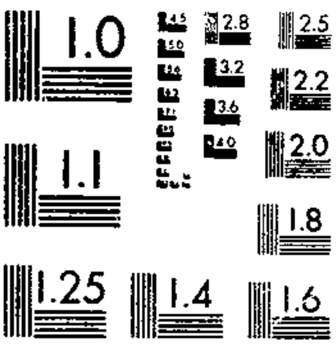

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Comparison of Methods of Supplying Phosphorus to Range Cattle[1]

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CONTENTS

INTRODUCTION

The feeding of phosphorus to range cattle to correct nutritional deficiencies had its beginning in studies made on the South African veld in 1924 by Thieler, Green, and Du Toit (*7*)[3] when they associated certain deficiencies in cattle with aphosphorosis, a condition caused by an insufficient phosphorus intake.

Phosphorus deficiencies in the early stages were recognized by depraved appetite, as evidenced by the chewing of bones and other

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[3] Italic numbers in parentheses refer to Literature Cited, p. 22.

materials. Advanced stages of the condition were manifested in impaired body growth and development and stiffness in the forequarters. This stage of aphosphorosis was termed "styfsekte" in South Africa and "creeps" in Texas and other localities in the United States (fig. 1). When the appetite of affected cattle became so depraved as to cause them to eat decomposed carcass material that was infested with an organism called *Clostridium botulinum*, a disease termed by the South Africans "lamsiekte" (*1*) resulted. This disease is referred to in the United States as loin disease and usually proves fatal.

Early experiments by South African investigators (*5*) showed that the feeding of bonemeal to breeding cattle increased the fertility of the cows, causing greater regularity in breeding, and also increased the milk flow, which in turn favored increased growth and skeletal development of the calves and prevented aphosphorosis.

Later experiments (*1*) showed that two-thirds of an ounce of dicalcium phosphate was as effective as 3 ounces of bonemeal or 2 ounces of disodium phosphate (20 percent P_2O_5) when fed by hand-dosing or mixed with salt or a palatable feed. The first-mentioned product is only slightly soluble in water and so cannot be administered satisfactorily through the drinking water. These experiments also showed that disodium phosphate was a satisfactory source of phosphorus when dissolved in the drinking water at the rate of approximately 1.5 ounces (10 gm. P_2O_5) to 5.8 gallons of water, the average quantity drunk per head daily.

Still further experiments in South Africa showed that the inorganic phosphorus level in the blood of cattle indicated whether the animals were receiving sufficient phosphorus to meet their requirements.

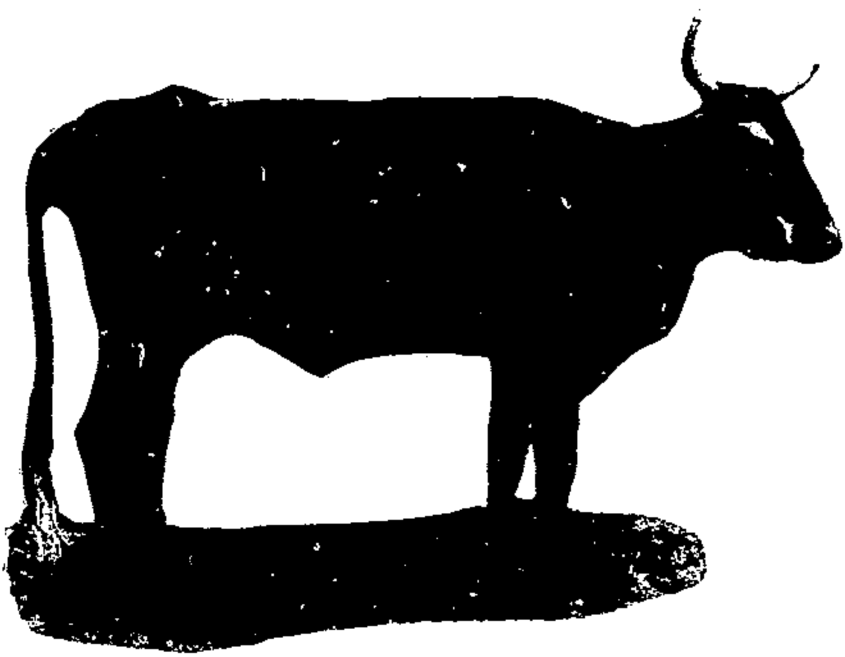

FIGURE 1.—Cow in "creepy" condition due to aphosphorosis.

These investigations showed that the phosphorus content of blood from cattle receiving adequate phosphorus ranged from 4 to 9 mg. per 100 cc. of whole blood, the younger the animal the higher the phosphorus content. The method for determining the inorganic phosphorus in whole blood was reported by Malan and Van Der Lingen (*6*) and has been employed in phosphorus deficiency studies in southern Texas.

Davidson (*4*) reports that phosphorus deficiency is closely associated with urinary calculi of steers in the Cypress Hills area of southwestern Saskatchewan, and recommends the feeding of bonemeal or monocalcium phosphate with good-quality alfalfa hay for the prevention of this condition. Incidentally, this trouble was not observed on the King Ranch in the coastal plain of Texas, where the present experiments were made.

In experiments conducted by Black, Ellis, Jones, and Keating (*3*) in west-central Texas, urinary calculi in the bladders of steers were commonly found when milo grain constituted the major carbohydrate portion of the fattening ration. The results of the tests indicated that the formation of urinary calculi could be controlled to a considerable degree and prevented in many instances by supplying additional phosphorus in the form of bonemeal. Over a 3-year period, a high percentage of the steers fed approximately 0.43 pound of bonemeal per head daily were free from calculi in the bladders at the end of a 182-day feeding period.

Experiments in southern Texas by Black, Tash, Jones, and Kleberg (*2*), in which breeding cattle on phosphorus-deficient range were hand-fed approximately 6.5 gm. of phosphorus per head daily (six times per week) when the cows were dry and 14.3 gm. during lactation, showed that aphosphorosis could be prevented and corrected if the phosphorus deficiencies were not too far advanced. Disodium phosphate and bonemeal, when fed so as to supply the same quantity of phosphorus, were of similar relative values as supplements to phosphorus-deficient vegetation.

The primary advantage in feeding a phosphorus supplement to cows under the conditions of these experiments was the increased percentage of the calf crops and greater weights attained by the cows and their offspring. These tests showed that only about 64 percent of the control cows produced calves as compared with 85 percent of those supplement fed. This difference was highly significant. Differences between the supplement-fed groups were not significant. The control cows weaned only a 58-percent calf crop, whereas the supplement-fed cows weaned 81 percent. Only slightly more than 30 percent of the control cows calved in 2 consecutive years, whereas the supplement-fed cows averaged about 73 percent. This difference was highly significant.

The feeding of phosphorus supplements to cows had no influence on the birth weights of calves, but the average weaning weight per calf in the supplement-fed group was 69 pounds more than in the control group, which was a considerable advantage. The difference in average weight between 12-month-old heifers in the supplement-fed and control groups was essentially the same as at weaning time, but at 18 months of age the supplement-fed heifers averaged 126 pounds heavier than the latter.

THE AREA AND ITS PROBLEMS

There are many phosphorus-deficient areas in the United States, particularly along the Gulf coast, the eastern seaboard, and a strip of country extending north from central Texas to well up into Saskatchewan and Alberta, Canada (fig. 2). The collection of numerous vegetative samples in southern Texas and their analyses in experiments (*2*) conducted from 1937 to 1941 revealed evidence of deficiencies in protein and phosphorus of considerable consequence. Few of the samples contained more than 0.12 percent of phophorus, and few had a calcium content of less than 0.24 percent. A phosphorus content of 0.13 percent and a calcium content of 0.23 percent of the dry matter of the vegetation consumed have been generally accepted as the minimum amounts of these elements required by range cattle. In many of these areas cattle get no feed other than the native range, and much of the time the vegetation is very dry. Records taken in the area where the mineral studies were under way generally showed the rainfall to be low each year in November and December. The annual rainfall in the area averages about 20 inches. In this same period the protein content of the plants is correspondingly low. When precipitation is low there is a tendency for plants to become somewhat stunted and mature early. When seeds begin to form there is a rather rapid movement of phosphorus from the stems and leaves to the seeds. The seeds shatter out, leaving a phosphorus-deficient forage for grazing. It was also found that considerable differences existed in the composition of different species and in the same species in different localities.

The calcium content of the vegetation is adequate in most instances and seemingly not affected materially by stage of growth or rainfall.

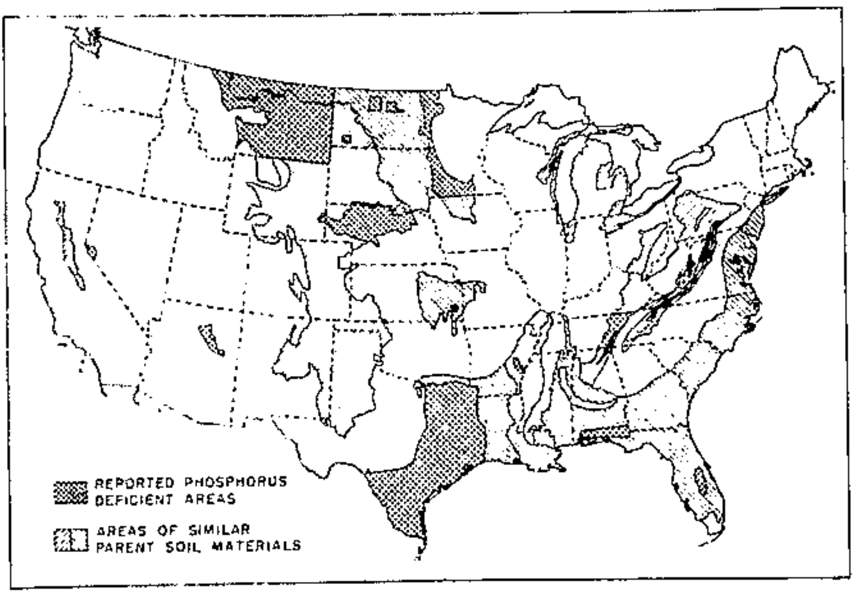

FIGURE 2.—Areas in the United States subject to phosphorus deficiency.

Inorganic phosphorus determinations of blood samples from cattle in several pastures verified the analyses of the grass samples as to the low phosphorus content of the forage. The protein content of the forage is usually low and appears to be closely associated with the phosphorus content, being highest in the early spring and lowest in midwinter.

The area wherein these investigations were conducted was in the nearly flat coastal plain of Texas bordering on the Gulf of Mexico. Climatic conditions in the Texas Gulf coast area vary from humid in the eastern part to subhumid and arid in the southern and western parts. Where the phosphorus supplements were supplied to cattle the conditions were semiarid and long droughts were not uncommon. The soil types vary from heavy clays to fine sands. The predominating grasses are species of *Paspalum*, of which the honeydew or Georgia grass is the most important, and the *Andropogon* species, called sage grasses. Of lesser importance are buffalo grass, hairy grama, sandhill grass, and big saltgrass or sacahuista.

Except during periods of drought, there was usually an abundance of vegetation that supported greater numbers of cattle per section than did most other range areas of Texas. The cattle in the area are for the most part undersized owing largely to nutritional deficiencies in the vegetation. A persistent craving by many cattle for bones, dirt, wood, and other materials, indicating a phosphorus deficiency, is usually in evidence in times of drought where cattle are compelled to exist on the vegetation alone. The animals affected with this deficiency disease become thin and weak and move with a peculiarly stiff, creepy gait.

The studies (2) from 1937 to 1941 showed conclusively that by the feeding of phosphorus supplement to range cattle nutritional deficiencies could be controlled and prevented in most instances, thereby resulting in a greater percentage of calf crops and heavier calves at weaning time. However, there remained the problem of determining the relative values of practical methods of supplying this supplement. Accordingly, the experiment reported herein was designed to compare direct self-feeding methods with the indirect method of supplying phosphorus through fertilization of pastures in areas deficient in this element.

EXPERIMENTAL PROCEDURE

This experiment was conducted from July 1941 to November 1946 at the King Ranch, Kingsville, Tex., by the Bureau of Animal Industry of the United States Department of Agriculture, the Texas Agricultural Experiment Station, and the King Ranch. The Tennessee Valley Authority furnished the superphosphate used for pasture fertilization. The soil was largely Nueces fine sand, a loose sand subject to wind erosion but not to water erosion.

Four groups of heifers approximately 20 months of age and of Brahman × Hereford breeding (fig. 3) were divided at random and placed on 640-acre pastures. Groups 1, 2, and 3 averaged 42 head per year and group 4, about 50 percent more. The animals were handled as follows:

Group 1 (controls). On native range with no mineral supplement.

Group 2. On native range with access to bonemeal placed in well distributed self feeders, *Group 3.*—On native range and receiving supplemental phosphorus from disodium phosphate (20 percent P_2O_5) dissolved in the drinking water in such quantity as to provide 6.5 gm. of phosphorus (14.88 gm. P_2O_5) in 6 gallons of water.

Group 4.—On native range fertilized in July 1941 with triple superphosphate applied at a rate of 200 pounds per acre (96 pounds of P_2O_5). However, as about 12 percent of the 640-acre pasture was brush covered and not fertilized, aproximately 113,280 pounds was applied to the open areas, which amounted to 177 pounds per acre for the section or 200 pounds per acre for about 566 acres.

The three unfertilized areas used by groups 1, 2, and 3 were stocked at the rate of approximately 1 cow to 15 acres, whereas the fertilized area grazed by group 4 was stocked at a 50-percent greater rate, or approximately 1 cow to 10 acres. The numbers were slightly reduced between April 1943 and June 1945. Santa Gertrudis bulls were used with all groups. Approximately 20 cows were allotted to 1 bull.

FIGURE 3.—Brahman × Hereford heifers selected in July 1941 for experiments on methods of supplying phosphorus to range cattle.

Individual weights of all experimental cattle were taken at monthly intervals through April 1944 and thereafter every 3 months. In addition, weights of cows at time of weaning calves were taken after April 5, 1944. Individual weights were obtained for all calves when weaned at approximately 240 days of age. Blood samples were taken at 28-day intervals from 10 representative cows in each group. The whole blood was used for inorganic phosphorus determinations, the method described by Malan and Van Der Lingen (*6*) being used.

Forage samples were collected at rather regular intervals throughout the test. An attempt was made to obtain material similar to that being eaten by the cattle at the time. The samples were sent to the Texas Agricultural Experiment Station for protein, calcium, and phosphorus determinations.

All physical equipment, including cattle, fenced pastures, corrals, scales, mineral supplements, and much of the labor involved in conducting the study, was furnished by the King Ranch. The Bureau of Animal Industry of the United States Department of Agriculture and the Texas Agricultural Experiment Station supervised the project, collected and analyzed the forage and blood samples, and were responsible for the technical phases of the experimental work in general.

RESULTS OF EXPERIMENTS

Analyses of Forage

The protein, calcium, and phosphorus contents of the vegetative samples taken from the experimental pastures are shown in table 1. In comparatively few instances was the calcium content below 0.20 percent or the phosphorus content above 0.15, thus indicating sufficient calcium but a deficiency of phosphorus. The samples with a phosphorus content above 0.15 were for the most part from fertilized areas. The protein and phosphorus content of most of the species analyzed tended to be lowest during winter and drought periods, when there was the least green feed. The protein content was seldom above 8 percent and averaged only about 4 percent for most species analyzed. The calcium content was seemingly not affected by the rainfall. The annual rainfall ranged from approximately 17 to 25 inches and averaged about 20 inches for the 5-year period 1942–46 in the immediate area where the investigation was conducted. The average monthly rainfall on the experimental pastures is shown in table 1. The relation between average monthly rainfall and percentage of protein and phosphorus in the most important grass (*Paspalum plicatulum*) in the experminental pastures is shown in figure 4.

The figure shows that both the protein and phosphorus contents of the vegetation are rather closely associated with rainfall. In general increased seasonal rainfall over a 3-month period, for example, was reflected in higher protein and phosphorus percentages in the vegetation for about the same period.

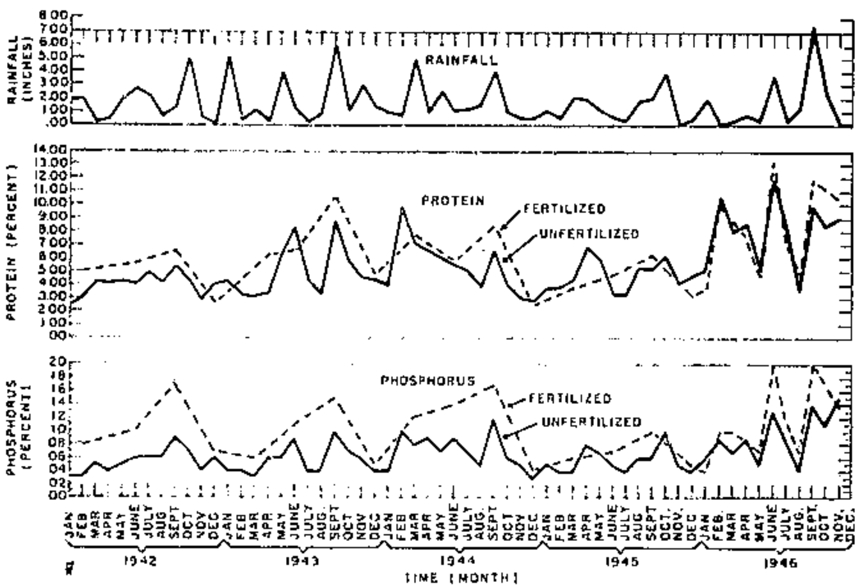

Figure 4.—Relation between average monthly rainfall and percentages of protein and phosphorus in fertilized and unfertilized vegetation (*Paspalum plicatulum.*)

In 1945 with a low annual rainfall of 16.77 inches, 12 samples of *Paspalum plicatulum* taken monthly throughout the year had an average protein content of 4.78 percent and a phosphorus content of about 0.06 percent in the unfertilized vegetation, whereas in 1943 when the annual rainfall was 24.80 inches, the protein content averaged 5.30 percent, with no increase in the percentage of phosphorus, indicating the lack of available phosphorus in soluble form in the soil. Four samples of the vegetation taken in March, June, September, and December 1943 from the fertilized areas had an average phosphorus content of 0.09 as compared with only 0.07 for the same months of 1945. In 1946, when the rainfall was about the average, and following a comparatively dry year, 10 samples of *Paspalum plicatulum* from the fertilized areas had a phosphorus content of 0.11, as compared with 0.09 for the unfertilized vegetation. This finding indicates that some available phosphorus still remained in the soil as a result of the application of triple superphosphate in the summer of 1941, but according to present standards even this higher level of phosphorus was not adequate for normal requirements of range cattle when subsisting solely on the range. Figure 4 shows that the phosphorus content of the fertilized grass was consistently higher for essentially the duration of this study, the only exceptions being in two or three instances during the dry year of 1945.

TABLE 1.—*Average protein, calcium, and phosphorus content, on an air-dry basis, of some of the more important forage plants consumed by the cattle in the experiment and rainfall during the experimental period*

Year and month [1]	*Paspalum plicatulum*			*Andropogon littoralis*			*Paspalum setaceum*			*Eragrostis secundiflora*			*Brachiaria ciliatissima*			*Elyonurus tripsacoides*			Rainfall
	Protein	Calcium	Phosphorus	Protein	Calium	Phosphorus	Protein	Calcium	Phosphorus	Protein	Calcium	Phosphorus	Protein	Calcium	Phosphorus	Protein	Calcium	Phosphorus	
1942	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Inches*
January	2.71	0.35	0.03	3.11	0.23	0.03							4.38	0.39	0.04				1.85
February	2.96	.39	.03	2.70	.26	.03							5.11	.52	.05	3.33	0.19	0.04	1.98
	5.07	.35	.08	5.15	.32	.08													
March	4.45	.41	.05	5.48	.28	.07										3.68	.27	.04	.17
April	4.22	.31	.04	3.60	.23	.05	7.63	0.64	0.09	5.82	0.23	0.21				3.52	.25	.05	.48
May	4.42	.40	.05	3.56	.31	.05	6.24	.48	.08	5.71	.23	.07							1.98
June	4.04	.21	.06	3.09	.22	.05	4.95	.41	.07	5.16	.19	.07	6.67	.41	.08	4.41	.19	.06	2.64
	5.33	.41	.10				5.82	.56	.10										
July	4.92	.41	.06	4.75	.24	.06	6.56	.57	.08	5.60	.20	.07	6.83	.43	.10	4.53	.20	.08	2.26
August	4.22	.44	.06	2.98	.14	.05	7.63	.45	.04	3.80	.19	.05	3.99	.42	.05				.63
September	5.74	.35	.09	5.30	.26	.07	9.34	.67	.15	7.20	.24	.10							1.40
	6.55	.46	.17				7.60	.66	.16										
October	4.63	.36	.07	3.24	.33	.07	8.69	.66	.15	6.39	.29	.14				5.28	.26	.07	4.99
November	2.95	.29	.04	3.58	.14	.05	5.16	.59	.06	5.02	.16	.07				4.34	.17	.06	.52
December	4.15	.32	.06	2.34	.25	.06	6.11	.63	.07	4.60	.25	.06							.09
	2.66	.25	.07	2.83	.24	.08	5.13	.59	.12	3.64	.19	.09							
1943																			
January	4.45	.31	.04	3.53	.26	.03	7.20	.64	.07				9.14	.56	.07	2.90	.14	.03	5.25
February	3.62	.39	.04	3.01	.26	.03							6.04	.47	.07	3.15	.14	.03	.21
March	3.19	.34	.03	3.45	.24	.04	7.34	.51	.10				11.79	.49	.12				1.18
	3.32	.34	.06	4.83	.24	.09	6.03	.49	.12				6.91	.41	.15				
April	6.26	.41	.06	5.93	.29	.07							5.98	.31	.09				.17
May	6.35	.54	.06	4.55	.22	.05	5.65	.50	.06	5.65	.22	.06							4.03
June	8.39	.39	.09	4.81	.26	.06	6.68	.57	.07	6.00	.21	.06	6.37	.44	.07				1.23
	6.78	.47	.11	6.42	.23	.13	5.24	.51	.13	4.90	.21	.11	5.26	.39	.12				
July	4.39	.33	.04	3.52	.24	.04	5.04	.59	.06				8.50	.52	.07				.24
August	3.26	.48	.04	2.61	.22	.02				3.14	.19	.04	3.59	.36	.04	2.74	.19	.03	.78
September	8.80	.44	.10				11.53	.64	.17				8.29	.39	.10				5.90
	10.74	.49	.15				10.65	.63	.18				9.04	.41	.17				
October	5.94	.39	.07	3.64	.24	.04	5.50	.32	.06	6.70	.16	.08				4.27	.22	.06	1.22
November	4.55	.35	.06	3.65	.25	.04				4.55	.23	.06				3.58	.19	.04	3.13
December	4.46	.35	.04	3.54	.24	.04	8.33	.63	.09	4.05	.21	.05							1.46
	4.82	.33	.05	4.70	.21	.04	6.54	.44	.08	5.12	.22	.06							

[1] See footnote 1, p. 11.

TABLE 1.—*Average protein, calcium, and phosphorus content, on an air-dry basis, of some of the more important forage plants consumed by the cattle in the experiment and rainfall during the experimental period*—Continued

Year and month [1]	*Paspalum plicatulum*			*Andropogon littoralis*			*Paspalum setaceum*			*Eragrostis secundiflora*			*Brachiaria ciliatissima*			*Elyonurus tripsacoides*			Rainfall
	Protein	Calcium	Phosphorus	Protein	Calcium	Phosphorus	Protein	Calcium	Phosphorus	Protein	Calcium	Phosphorus	Protein	Calcium	Phosphorus	Protein	Calcium	Phosphorus	
1944	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Inches*
January	3.90	0.41	0.04	4.49	0.24	0.04				4.50	0.24	0.05				3.14	0.19	0.04	0.98
February	9.80	.44	.10	8.23	.29	.10	12.66	0.61	0.12										.22
March	7.13	.44	.08	4.67	.25	.06	6.30	.42	.08				6.44	0.35	0.08				5.00
	7.86	.41	.12	6.69	.25	.11	7.22	.49	.16				4.60	.23	.09				
April	6.65	.45	.09	6.22	.29	.08	6.05	.50	.08										.93
May	6.01	.50	.07	5.50	.32	.07	4.35	.54	.07	5.10	.29	.07	4.80	.33	.06				2.57
June	5.65	.40	.09	4.85	.24	.10	4.50	.44	.06				4.10	.34	.07				1.08
	5.81	42	.14	4.73	.26	.09	4.29	.51	.08				4.60	.33	.10				
July	4.63	.60	.07	3.43	.16	.05	4.02	.56	.06				3.25	.40	.06				1.20
August	3.73	.49	.05	2.94	.36	.04							4.32	.42	.04				1.62
September	6.66	.42	.12	5.85	.23	.10	7.15	.52	.10										4.36
	8.52	.41	.17	6.25	.29	.13	9.56	.48	.15										
October	4.00	.38	.06				5.48	.36	.09	4.90	.13	.08	9.67	.38	.17				.96
November	3.09	.39	.05	2.47	.16	.03	3.80	.33	.08	3.69	.26	.06				3.80	.14	.06	.60
December	2.70	.36	.03	2.27	.16	.03				2.91	.15	.03	8.74	.43	.08				.58
	2.55	34	.04	2.43	.24	.04				2.55	.17	.04	6.71	.53	.13				
1945																			
January	3.70	.42	.05	2.55	.20	.03				3.13	.24	.04	4.98	.43	.06				1.08
February	3.90	.36	.04	3.35	.24	.04	7.55	.65	.13										.60
March	4.40	.34	.04	3.60	.21	.04	6.86	.51	.09				7.79	.29	.16				2.14
	3.94	.41	.06	2.70	.19	.04	5.52	.47	.10				5.96	.31	.14				
April	6.85	.44	.08	3.90	.19	.03	7.25	.48	.12				8.70	.35	.14				2.05
May	5.85	.47	.07	5.05	.25	.06	4.60	.40	.05				8.25	.24	.10				1.29
June	3.30	.39	.05	2.95	.19	.04	3.87	.46	.05				5.08	.39	.07				.61
	4.80	.45	.07	3.90	.31	.07	5.28	.51	.11				5.70	.42	.09				
July	3.34	.42	.04	4.00	.22	.06	4.44	.51	.05				5.09	.44	.07				.37
August	5.40	.34	.06	4.23	.23	.05	6.58	.47	.07				8.80	.33	.10				1.91
September	5.35	.36	.06	4.69	.21	.04	6.31	.37	.08				7.07	.34	.08				2.10
	6.38	.39	.10	6.26	.24	.08	8.43	.51	.13				6.45	.29	.11				
October	6.31	.39	.10	6.29	.33	.10	6.40	.54	.10	6.95	.14	.10	8.31	.26	.10				4.08
November	4.20	.24	.05	4.64	.24	.05	6.26	.46	.07				7.38	.32	.08				.00
December	4.70	.32	.04	3.73	.26	.04				4.46	.16	.04							.54
	3.23	.26	.05	3.18	.39	.05				3.77	.21	.05							

1946																			
January	5.28	.49	.06	3.71	.24	.04													2.03
	3.74	.38	.04	3.95	.27	.04													
February	10.83	.40	.09	5.40	.26	.06													.00
	10.15	.41	.10	7.23	.31	.09													
March	7.92	.49	.07	6.98	.29	.08													.31
	8.70	.48	.10	7.00	.34	.10													
April	8.61	.46	.09	5.94	.28	.07													.89
	7.80	.48	.09	6.60	.35	.10													
May	5.24	.41	.05	4.60	.31	.05													.46
	4.60	.34	.07	4.30	.36	.06													
June	12.06	.54	.13	8.40	.24	.10	13.52	.71	.15										3.82
	13.39	.59	.20	10.76	.29	.14	17.01	.64	.23										
July	8.58	.48	.09	6.82	.30	.08													.40
	7.37	.60	.12	6.54	.38	.10													
August	3.49	.25	.04																1.44
	4.80	.32	.07																
September	10.00	.47	.14				8.70	.54	.12										7.75
	11.90	.51	.20				10.92	.74	.23										
October	8.40	.36	.11				10.84	.44	.13										2.48
							5.51	.25	.12										
November	9.10	.49	.15				7.55	.54	.10										.00
	10.62	.50	.14				11.80	.56	.14										

[1] When two sets of data are given for 1 month, the lower set was obtained from samples from fertilized areas. In all other instances the data are from unfertilized areas.

Inorganic Phosphorus in Whole Blood

The average amounts of inorganic phosphorus in whole-blood samples taken at regular intervals are shown in figure 5. In only a few instances did the inorganic phosphorus content of the blood of the

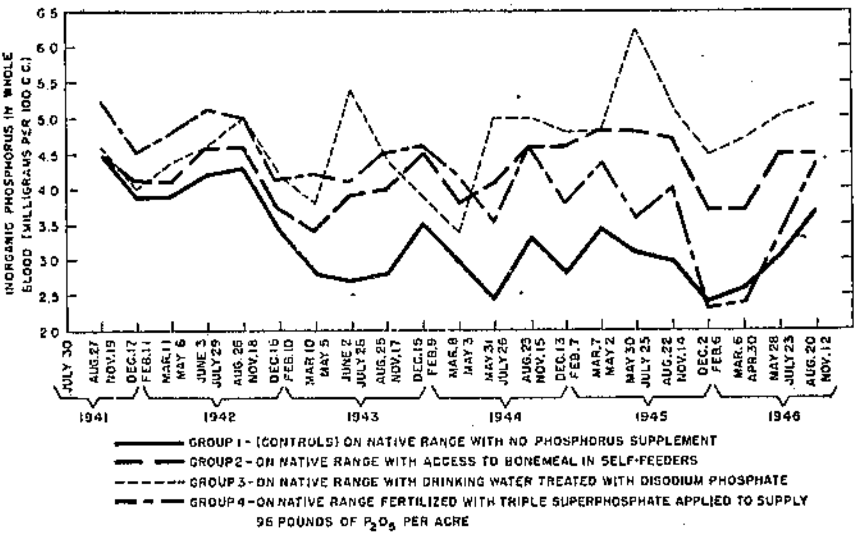

Figure 5.—Average inorganic phosphorus in whole-blood samples taken from cows at regular intervals during the experiment.

control cows (group 1) rise above 4 mg. per 100 cc. of whole blood,[1] which is considered the minimum amount for cows without showing evidence of effects of phosphorus deficiency. As a rule these followed heavy rainfall, when there was an abundance of fresh green grass or when most of the samples were from dry cows.

The blood samples from the cows in group 3, which received phosphorus through the use of disodium phosphate dissolved in their drinking water, had the most consistent uniformly high phosphorus level. After November 1942, this group had the highest blood-phosphorus level for most of the remainder of the experiment, the one principal exception being from November 1943, to May 1944, when the cows in group 2, fed bonemeal, and those in group 4, grazing the fertilized pasture, had slightly higher blood-phosphorus levels. In only two instances did the phosphorus level of the group 3 cows drop below 4 mg., and then for only very short periods in cows with large calves. The cows receiving bonemeal from self-feeders (group 2) maintained a safe phosphorus level for most of the time. Only occasionally did the phosphorus drop below 4 mg. per 100 cc. of whole blood, and when this occurred it was usually associated with lactating cows that seemingly did not consume sufficient bonemeal to meet their phosphorus requirements during the time when their calves were the heaviest drain on them. On the other hand, some cows in the group apparently consumed considerably more bonemeal than they needed.

[1] Inorganic phosphorus is usually somewhat lower in whole blood than in serum.

The phosphorus content of the blood from cows in group 4, which grazed the fertilized pasture, showed a downward trend after the first year. It was close to or below 4 mg. per 100 cc. of blood most of the time after May 1944, showing rapid declines practically every time grazing conditions became adverse. The phosphorus content was extremely low following the dry summer of 1945 and reached a dangerously low point of about 2.25 mg. in the midwinter of 1945–46. Physical symptoms of aphosphorosis were common among the lactating cows in this group during this period. It was always possible to diagnose aphosphorosis definitely in the cows in group 1, which grazed unfertilized range and received no phosphorus supplement, and in group 4, which grazed the fertilized range, by blood analyses before actual clinical symptoms of the condition appeared. Figure 5 shows that the blood phosphorus levels of these two groups paralleled each other very closely after the first year of the experiment.

Relation of Cattle Weights to Phosphorus Intake

The average initial weights and successive yearly weights of the cows in each group, the average weaning weights of the calves at approximatly 240 days, the weights of their dams at time of weaning, and the quantities of phosphorus supplement used are shown in table 2. The daily phosphorus intake per cow in groups 2 and 3 is shown in figure 6.

A comparison of the control group and groups 2 and 3, fed supplemental phosphorus, shows that the initial weights of the cows were essentially the same at the beginning of the test, and there were no essential differences at the end of the first year ending in November 1942. The greatest difference was between the control cows and those

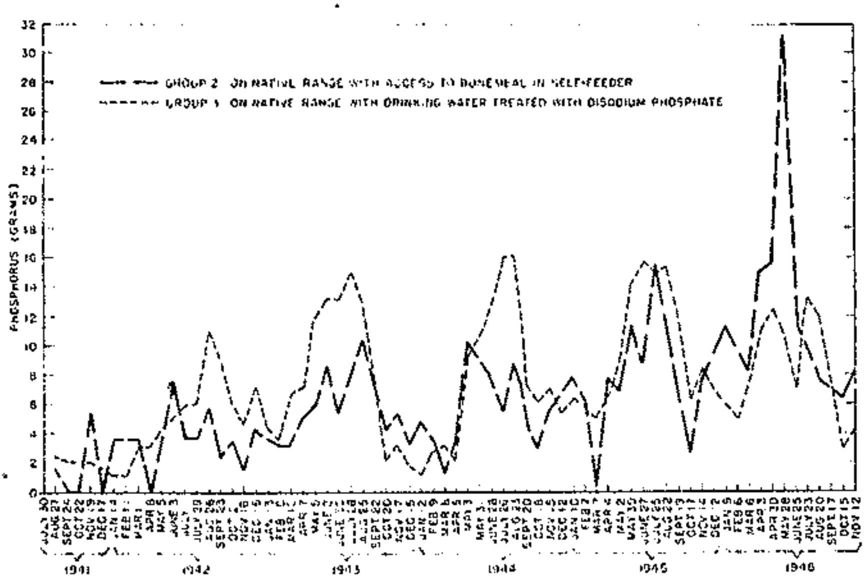

Figure 6.—Grams of phosphorus consumed per cow daily in groups 2 and 3.

grazing the fertilized pasture, the latter averaging 65 pounds more at the end of the first year. By the end of the third year the cows on the fertilized pasture averaged 293 pounds more than the control cows, and 53 and 57 pounds more, respectively, than the cows fed bonemeal and those fed disodium phosphate in the drinking water. After the third year, however, the cows in these two groups were heavier than those in group 4, indicating that the fertilizer was losing its effectiveness. At the end of the fifth year the differences between the controls and other groups were smaller than at any time after the first year. These average yearly weights for all cows in each group do not reveal the true picture, however, as there was always a higher percentage of dry cows in the control group. Dry cows have a tendency to carry more flesh than lactating cows, and accordingly this control group, owing to a lower percentage calf crop, would possess a little more average weight per cow than would have been the case had more of them produced calves.

TABLE 2.—*Average initial weights and succeeding yearly weights of the cows in each group, weaning weights of calves, weights of their dams at time of weaning, and quantities of supplements supplied*

Item	Group 1 (no phosphorus supplement)		Group 2 (bonemeal in self-feeders)		Group 3 (disodium phosphate in drinking water)		Group 4 (range fertilized with triple superphosphate)	
	Cows	Calves	Cows	Calves	Cows	Calves	Cows	Calves
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Average initial weight of cows	706	--------	708	--------	708	--------	705	--------
Average weight of cows at end of—								
First year	1, 077	--------	1, 087	--------	1, 050	--------	1, 142	--------
Second year	910	--------	1, 029	--------	1, 051	--------	1, 106	--------
Third year	867	--------	1, 107	--------	1, 103	--------	1, 100	--------
Fourth year	882	--------	1, 140	--------	1, 155	--------	1, 107	--------
Fifth year	1, 047	--------	1, 148	--------	1, 195	--------	1, 100	--------
Average weights of cows and calves at weaning time:								
First calf crop	774	500	939	524	956	529	993	544
Second calf crop	825	500	1, 043	516	1, 028	533	1, 052	502
Third calf crop	789	400	1, 015	546	1, 039	519	1, 007	557
Fourth calf crop	878	497	1, 048	556	1, 009	590	1, 007	542
4-year average	802	489	1, 011	535	1, 029	542	1, 015	551
Supplement or fertilizer used per cow at end of—								
First year	--------	--------	27	--------	49	--------	1, 880	--------
Second year	--------	--------	47	--------	77	--------	--------	--------
Third year	--------	--------	45	--------	70	--------	--------	--------
Fourth year	--------	--------	62	--------	89	--------	--------	--------
Fifth year	--------	--------	99	--------	80	--------	--------	--------
5-year total	--------	--------	250	--------	365	--------	1, 880	--------
Average per year	--------	--------	50	--------	73	--------	376	--------

The weights of the cows that weaned calves, at the time their calves were taken from them, give a much truer picture of the comparative weights of cows in each of the groups. At the time of weaning the first calf crop, the control cows averaged 219 pounds less per head than the cows that grazed the fertilized pasture and 165 pounds and 182 pounds, respectively, less than the cows fed bonemeal and disodium phosphate. At the time of weaning the second calf crop, the cows on the fertilized pasture that weaned calves averaged 227 pounds more than the control cows. Differences between the controls and the other two groups were slightly less. The cows that received phosphorus in their drinking water were the heaviest of any of the groups at the time of weaning their third calf crop and continued to be so for the remainder of the experiment. At the time of weaning their fourth calf crop these cows averaged 221 pounds more per head than the controls, 51 pounds more than those fed bonemeal, and 92 pounds more than those on the fertilized pasture. This extra poundage would bring considerable additional revenue to the producer if the cows were to be disposed of for market purposes. In addition, these heavier cows because of supplemental feeding produced much heavier calves at weaning time.

The calves from the control group were the lightest in weight each year, and with one exception (the fourth calf crop) the calves from the cows on the fertilized pasture were the heaviest. For the four calf crops the calves from the fertilized pasture group averaged 62 pounds more per head than those from the control cows, 16 pounds more than those from the cows fed bonemeal, and 9 pounds more than those from the group receiving phosphorus through the drinking water.

Table 2 shows that the general trend of the phosphorus intake by groups 2 and 3 was upward as the experiment progressed. When the average amounts of bonemeal or disodium phosphate consumed by groups 2 and 3 for the 5-year period are converted to phosphorus, the cows in group 2 consumed 6.8 gm. of phosphorus per head daily throughout the experiment and the cows in group 3 utilized 8.9 gm.

As shown by the table, about 376 pounds of superphosphate per year was used on the pasture grazed by the cows in group 4. In terms of phosphorus, this amounts to about 100 gm. per cow daily.

Figure 6 indicates a general increase in the consumption of the supplements during the midsummer, when rainfall is usually at a low point and the grass is in a low productive state. The extremely high points of consumption, such as nearly 32 gm. of phosphorus per head daily by group 2 in May 1946, immediately followed the end of the severe drought extending back to October 1945 (fig. 4).

Calf Production

The percentage of calf crops, average weaning weights of calves, and value of weaned calves for the four groups are given in table 3. The percentage calf crops with few exceptions were highest in each of the four groups for the first two crops of calves. For the third calf crop, there were slightly reduced percentages in the groups supplied phosphorus through the drinking water and grazing the fertilized range and about 15 percent reduction in the control group. The group fed bonemeal, however, showed no reduction. For the control cows the calf crop in the fourth year dropped to 22 percent as compared with an average of about 84 percent for the first three crops. For groups 2 and 3 the decline in calf crop in the fourth year was only 5 and 2 percent respectively. In group 4 the percentage calf crop was the same as the average for the 3 preceding years.

TABLE 3.—*Calf production data of the 4 experimental groups*

Item	First calf crop	Second calf crop	Third calf crop	Fourth calf crop	Average of four calf crops
Group 1 (no supplemental phosphorus):					
Cows .... number	43	42	42	40	42
Calf crop .... percent	91	88	74	22	69
Calves weaned .... do	86	83	67	22	64
Average weaning weight per calf .... pounds	500	500	460	497	489
Weaned-calf weight per cow .... do	430	416	307	112	319
Weaned-calf weight per acre .... do	29	27	20	7	21
Value of weaned calf per acre .... dollars [1]	4.35	4.05	3.00	1.05	3.12
Group 2 (bonemeal, self-fed):					
Cows .... number	43	43	43	40	42
Calf crop .... percent	93	93	93	88	92
Calves weaned .... do	86	88	94	85	88
Average weaning weight per calf .... pounds	524	510	515	550	535
Weaned-calf weight per cow .... do	451	456	495	473	468
Weaned-calf weight per acre .... do	30	31	33	30	31
Value of weaned calf per acre .... dollars [1]	4.50	4.65	4.95	4.50	4.64
Group 3 (disodium phosphate in drinking water):					
Cows .... number	43	42	42	40	42
Calf crop .... percent	98	98	95	95	96
Calves weaned .... do	93	95	88	92	92
Average weaning weight per calf .... pounds	529	533	519	590	542
Weaned-calf weight per cow .... do	492	508	457	540	499
Weaned-calf weight per acre .... do	32	33	30	34	33
Value of weaned calf per acre .... dollars [1]	4.95	4.95	4.50	5.10	4.89
Group 4 (fertilized pasture):					
Cows .... number	62	57	57	57	57
Calf crop .... percent	100	100	95	98	98
Calves weaned .... do	93	96	95	98	96
Average weaning weight per calf .... pounds	544	562	557	542	551
Weaned-calf weight per cow .... do	507	542	528	532	527
Weaned-calf weight per acre .... do	46	48	47	47	47
Value of weaned calf per acre .... dollars [1]	6.90	7.20	7.05	7.05	7.07

[1] Weaned calves valued at $0.15 per pound.

The cumulative effect of a deficiency of phosphorus on calf production is indicated by the decline in number of calves produced by the controls from year to year. The calf crop for this group ranged from a high of 91 percent in the first crop to a low of 22 percent in the fourth with an average of 69 percent for the four calf crops. The percentage calf crop in the groups receiving phosphorus remained rather consistent throughout the 4 years. The most pronounced decline was in the fourth crop, and this may be attributed to the dry season of 1945 during which time some cows failed to get with calf owing to their poor condition.

For the 4 years, the calves in the groups receiving phosphorus through the eating of bonemeal, drinking of water treated with disodium phosphate, and grazing of range fertilized with superphosphate had 46, 53, and 62 pounds, respectively, higher average weaning weights than those in the control group. Furthermore, the average weights of the cows at time of weaning the calves in these groups were 209, 227, and 213 pounds, respectively, more than those of the controls (table 2). The cows that consumed bonemeal produced an average of 149 pounds more weaned calf per cow and 10 pounds more calf per acre for each of the four calf crops than the cows in the control group, whereas the cows getting disodium phosphate in their drinking water produced 181 pounds more weaned calf per cow and 12 pounds more per acre, and those grazing the fertilized range produced 208 pounds more weaned calf weight per cow and 26 pounds more per acre than the control cows. The average increased weight of weaned calves per acre for the groups getting supplemental phosphorus over that of the control group amounted to $1.52 for the group fed bonemeal, $1.77 for the group receiving disodium phosphate, and $3.95 for the group on fertilized pasture.

The cows supplied with phosphorus directly by supplementation or indirectly through fertilized vegetation got settled in calf more readily than the nonsupplemented group, as shown by table 4.

During the experiment cows in all the groups had equal opportunity to conceive and drop four or five calves. The amount of time between conceptions, as determined from the average dates of the calvings, was materially greater for the control group than for any of the groups getting phosphorus supplements. Although the group on fertilized pasture had a greater number of cows than the group that received no additional phosphorus supplement, this larger group of cows was almost 3 weeks earlier in getting settled in calf the first year than the smaller groups. This immediate effect is also noted for the other two groups that were given a phosphorus supplement.

For groups 2, 3, and 4, getting additional phosphorus, the average time between calvings was 1 year, or approximately 100 days less than for the control group. By the end of the experiment, all the fourth calves and some of the fifth calves had been dropped in groups 2, 3, and 4, whereas in group 1 so much time had been required for conceptions that only 10 cows in that group had dropped their fourth calf.

TABLE 4.—*Average dates of calvings and average number of days between successive calves for each of the groups*

Item	Group 1 (no phosphorus supplement)	Group 2 (bonemeal in self-feeders)	Group 3 (disodium phosphate in drinking water)	Group 4 (fertilized pasture)
Average date of first calf in 1943	Feb. 11	Feb. 3	Jan. 22	Jan. 21
Average number of days between first and second calves	444	387	376	368
Average date of second calf in 1944	Apr. 30	Feb. 25	Feb. 3	Jan. 24
Average number of days between second and third calves	467	358	370	377
Average date of third calf in 1945	Aug. 9	Feb. 17	Feb. 6	Feb. 4
Average number of days between third and fourth calves	348	314	346	344
Average date of fourth calf in 1946	July 21	Jan. 27	Jan. 10	Jan. 13
Average number of days between all calvings	459	365	367	364

GENERAL DISCUSSION

The general condition of the cows in each group at approximately the midpoint of the experiment (November 1944) is indicated in figures 7, 8, 9, and 10. It is clearly evident that the supplement-fed groups and the group on the fertilized pasture were in better condition than the control cows, as several cows in the control group showed evidence of aphosphorosis. There was no material difference in the general appearance of the groups getting additional phosphorus by supplementation and the group grazing fertilized pasture, except in the last year when the group on fertilized range was somewhat inferior in condition to the other two groups.

F[illegible] Group 1 [illegible] unfertilized phosphorus-deficient pasture and receiv- [illegible] Note [illegible] condition indicating aphosphorosis in [illegible] cows [illegible]

FIGURE 8.—Group 2 cows on unfertilized pasture and supplied bonemeal in self feeders. Note thriftiness of the cows.

FIGURE 9.—Group 3 cows on unfertilized range area supplied phosphorus by dis- [illegible] phosphate in the drinking water. Note fleshy condition and [illegible]

FIGURE 10.—Group 4 cows on range fertilized in 1941 with a triple superphosphate applied to provide 96 pounds of P_2O_5 per acre. Note high condition of cows and increased growth of vegetation as compared with the unfertilized areas used by groups 1, 2, and 3 (figures 7, 8, and 9).

Production and cost data and returns for the complete experiment (1941–46) are summarized in table 5. The group grazing the fertilized pasture, stocked approximately 50 percent greater than the other pastures, produced about 48 percent more weaned calf weight than either the group fed bonemeal from self-feeders or the one fed disodium phosphate in the drinking water, and about 126 percent more than the control group. In weaned calf weight per cow, however, the group on fertilized range produced only about 12 percent more than group 2 and 5 percent more than group 3. The cows in the groups fed phosphorus directly or indirectly, however, averaged 56 percent more weaned calf weight per cow than the control group getting no additional phosphorus. This difference was highly significant. In weaned calf weight per acre, groups 2, 3, and 4 averaged about 78 percent more than the control group.

TABLE 5.—*Summary of production and cost data and returns for the complete experiment (1941–46)*

Item		Group 1 [illegible]	Group 2 [illegible]	Group 3 disodium phosphate in drinking water	Group 4 pasture fertilized with triple superphosphate
[illegible]	[illegible]	[illegible]	[illegible]	164	220
Weaned [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	120,704
Weaned [illegible]	[illegible]	[illegible]	[illegible]	2,000	2,408
Weaned [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	489
Value [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18,406
Value [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Value [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	28.20
Phosphorus [illegible]	[illegible]		12,042	[illegible]	113,280
Phosphorus [illegible]	[illegible]		[illegible]	[illegible]	1,880
Phosphorus [illegible]	[illegible]		[illegible]	21	177
Cost of phosphorus [illegible]	dollars		[illegible]	[illegible]	1,484.91
Cost of phosphorus [illegible]	dollar		[illegible]	[illegible]	22.76
Cost of phosphorus [illegible]	[illegible]		[illegible]	[illegible]	[illegible]
Net return [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	243.44
Net return [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23.44

[illegible]
[illegible]
[illegible]
[illegible]

The average value of the weaned calf weight for the supplement-fed and fertilized-pasture groups amounted to 56 percent more on the basis of calf weight per cow and 77 percent more on the basis of calf weight per acre than for the control group. Differences on the basis of calf weight per cow between the groups getting additional phosphorus were not great, whereas the differences between these groups and the controls were significant.

In terms of phosphorus, the amount consumed by the cows fed bonemeal was 5.6 pounds per head per year and by the cows supplied disodium phosphate in the drinking water, 6.4 pounds. If the phosphorus applied to the pasture used by group 4 had been completely utilized during the entire experimental period, nearly 78.6 pounds would have been consumed per cow per year. Although there were indications that the phosphorus in the soil was seriously depleted at the end of the experiment, as determined by blood and vegetative analyses and the condition of the cattle, yet these conditions may not have been due entirely to low phosphorus content in the soil, as the vegetative growth during the last year and a half of the experiment was much below normal owing to low rainfall in this period.

At the prices of the supplements and fertilizer used in this experiment, the cost of the bonemeal fed to group 2 amounted to $1.71 per cow per year; of the disodium phosphate fed to group 3, $2.78; and of the superphosphate on the fertilized pasture of group 4, $14.55. After the cost of supplements or fertilizer used had been deducted, the cows in group 3 returned $57.22 per head for each of the 5 years; those in group 2 returned $54.51; those in group 4, $48.69; and those in group 1, $38.34.

When the value of weaned calf weight is prorated on a per acre basis, the fertilized area because of its higher rate of stocking (50 percent greater than the others) made a return, after deduction of cost of supplement or fertilizer, of $4.29 per acre per year, as compared with $3.73 per acre for the group receiving disodium phosphate, $3.60 for the group fed bonemeal, and $2.50 for the control group.

SUMMARY AND CONCLUSION

An experiment was conducted cooperatively by the Bureau of Animal Industry of the United States Department of Agriculture, the Texas Agricultural Experiment Station, and the King Ranch in southern Texas from July 1941 to November 1946 for the purpose of comparing methods of supplying phosphorus to range cattle. Three groups were grazed on unfertilized native range—group 1 receiving no additional phosphorus; group 2 having access to bonemeal placed in well-distributed self-feeders; and group 3 supplied phosphorus through the use of disodium phosphate dissolved in the drinking water. A fourth group grazed range fertilized in July 1941 with triple superphosphate. The pastures grazed by groups 1, 2, and 3 were stocked at the rate of approximately 1 cow to 15 acres, whereas the fertilized pasture grazed by group 4 was stocked at approximately a 50 percent greater rate.

The calcium content of the forage was usually sufficient, as it was seldom below 0.20 percent. On the other hand, the vegetation usually showed a deficiency of phosphorus, only occasionally being above 0.15

percent. For the most part, the samples from the fertilized pasture were higher in phosphorus than similar samples from the unfertilized areas. The protein content was seldom above 8 percent and averaged only about 4 percent. Both the protein and the phosphorus contents of the forage were closely associated with rainfall, being lowest during winter and drought periods, when there was little green feed. The rainfall ranged from a yearly low of about 17 inches to a high of 25 inches and averaged about 20 inches for the 5-year period in the immediate area in which the experiment was conducted.

To prevent phosphorus deficiency, the minimum amount of inorganic phosphorus in the blood of cattle should be above 4 mg. per 100 cc. of whole blood. The cows grazing the unfertilized native range with no additional phosphorus usually had less than this amount. The blood samples from the group supplied phosphorus through the drinking water had the most uniformly high phosphorus level. The cows fed bonemeal maintained a safe phosphorus level most of the time. Group 4 showed a downward trend in blood phosphorus after the first year, reaching dangerously low levels following the droughts in the summer of 1945 and the midwinter of 1945-46. However, for the greater part of the experimental period, these animals maintained a fairly normal amount of inorganic phosphorus in their blood. Physical symptoms of aphosphorosis characterized by creepy condition were common in this group among lactating cows toward the close of the experiment.

At the time of weaning the fourth calf crop, toward the close of the experiment, the group 3 cows that weaned calves averaged about 221 pounds more in weight than those that weaned calves in the control group, 51 pounds more than those in group 2, and 92 pounds more than those in group 4. The heaviest cows at the close of the test were in group 3, and their phosphorus intake was somewhat greater than those in group 2. The latter group consumed, on the average, 5.6 pounds of actual phosphorus per head per year, and the former group consumed 6.4 pounds. Differences in the weights of the calves from the three groups receiving phosphorus were not significant.

A decrease in percentage calf crop from year to year in the control group indicated a cumulative effect of phosphorus deficiency. In the groups getting additional phosphorus the calf crop was rather constant throughout the experiment, the one exception of importance being in the fourth year when there was some decrease, due in all probability to the dry season of 1945 during which time a number of cows did not get with calf because of their poor condition. As compared with the percentage calf crop of the control group, bonemeal feeding increased the calf crop by 33 percent for the experimental period, disodium phosphate in the drinking water by 39 percent, and pasture fertilization by 42 percent.

The weaned calf weight per cow per year on the basis of four calf crops was increased by 149 pounds by the use of bonemeal as a supplement, 181 pounds by disodium phosphate in the drinking water, and 208 pounds by fertilizing the range. Bonemeal feeding increased the weaned calf weight per acre by 48 percent, disodium phosphate in the drinking water by 57 percent, and pasture fertilization by 128 percent.

Supplying phosphorus by the methods employed in this experiment shortened the period between calvings. On the average, there was about 1 year between calvings in groups 2, 3, and 4, or approximately 100 days less than for the control group. To the end of the experiment groups 2, 3, and 4 had dropped four calf crops and part of the fifth, whereas the cows in the control group had barely completed their fourth.

With weaned calves valued at 15 cents per pound and after deducting the cost of phosphorus supplement or fertilizer, group 1 returned, on the average, $38.34 per cow per year for the 5-year period, or $2.50 per acre; group 2, $54.51 per cow, or $3.60 per acre; group 3, $57.22 per cow, or $3.73 per acre; and group 4, $48.69 per cow, or $4.29 per acre.

Under the conditions of this experiment involving a 5-year period, the supplying of phosphorus by fertilization of pasture gave the greatest returns per acre, but the use of disodium phosphate dissolved in the drinking water resulted in the highest net returns per cow. In the last year, however, the cows on the fertilized range were somewhat inferior in condition to the other two supplemented groups.

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