PHOSPHORUS STUDIES WITH RUMINANTS

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INTRODUCTION

Phosphorus deficiency in cattle and sheep has been reported from many parts of the world, including several areas of the United States. This deficiency is chiefly caused by a lack of phosphorus in the roughages fed, and is characterized by a syndrome of low plasma inorganic phosphorus, anorexia, low feed efficiency, and abnormal bone growth.

Since the discovery that this syndrome is caused by a low plane of phosphorus nutrition, many phosphorus-containing substances have been investigated as possible sources of supplemental phosphorus. For a considerable period of time steamed bone meal has been a preferred source of supplemental phosphorus. However, due to the increased demand for phosphorus supplements by both the poultry industry and the cattle industry in recent years, the supply of bone meal is insufficient to meet the demand and it has been necessary to find other sources of supplemental phosphorus.

A number of sources of supplemental phosphorus for ruminant animals have been investigated and evaluated as being either satisfactory or unsatisfactory. Satisfactory phosphorus supplements include steamed bone meal, dicalcium phosphate, monosodium phosphate, defluorinated rock phosphate, phosphoric acid, and monoammonium phosphate. Supplements found to be unsatisfactory as a source of phosphorus for ruminants include raw rock phosphate and superphosphate. Soft phosphate with colloidal clay is a possible source of supplemental phosphorus for ruminants and the cost is favorable. The phosphorus in colloidal clay has been shown to have a low availability when fed to chickens or swine, but no research has been reported where colloidal clay has been fed to ruminant animals.

While it is obvious that the cost per unit of phosphorus will vary with the source, it must also be recognized that the availability of phosphorus may vary depending on chemical combination or physical association with other compounds in the feed.

The various symptoms of phosphorus deficiency have been widely used to measure the plane of phosphorus nutrition. There remains a need, however, for comparisons of the relative sensitivity of the various tests at known levels of phosphorus intake from a source known to be readily available.

The experiments which are reported in this thesis were initiated to provide information relating to the following objectives: (1) to determine the level of phosphorus intake that is most desirable for comparing the availability of phosphorus from different sources; (2) to determine the most desirable measures of the state of phosphorus nutrition; and (3) to comparatively evaluate with cattle and/or sheep the availability of phosphorus contained in selected inorganic phosphates.

REVIEW OF LITERATURE

CATTLE

Phosphorus Deficiency Symptoms

According to Forbes and Johnson (1937) the typical symptoms of phosphorus deficiency are chewing of bones, wood and other rubbish; a general appearance of undernutrition; soreness, swelling and creaking of the joints; listless disposition; a lack of appetite; failure to make normal growth; and low blood plasma inorganic phosphorus.

Inorganic Phosphorus Levels in Blood

Payne *et al*. (1946) reported that the normal levels for blood serum inorganic phosphorus, in mg. percent, were 7.30, 4.76, 5.07, and 4.89 for Hereford yearling bulls, herd bulls, 2-year old heifers, and aged cows, respectively.

Haag and Jones (1935) found that the inorganic phosphorus content of the blood plasma of normal dairy cattle was 7.74, 7.68, 7.05, 6.48, and 5.2 mg. percent for six-months, twelve-months, eighteen-months, twenty-four-months, and mature dairy cattle respectively.

Palmer *et al*. (1930) observed that the inorganic phosphate of the blood of dairy calves increases (from 5.97 mg. percent at birth to 7.68 mg. percent at 150 days) until about six months old, after which a decrease occurs which continues until the normal range for mature cattle is reached (about 5.8 mg. percent). These investigators observed that a number of other factors can affect the level of plasma inorganic phosphorus.

At three-fourths of an hour after feeding, inorganic phosphorus in the blood plasma was increased by a maximum of 0.68 mg. percent, and at two and three-fourths hours after feeding, it was decreased by a maximum of 0.59 mg. percent. There was a pronounced drop one-half hour after exercise, this amounted to a drop of 2.23 mg. percent in the most extreme case reported. In two trials the ingestion of water caused a significant drop in plasma inorganic phosphorus.

use Black et al. (1943) found that aphosphorosis could be diagnosed from inorganic phosphorus determinations of the blood even before actual physical symptoms of the deficiency became apparent. They observed that dry range cows grazing on a range deficient in phosphorus always had a monthly average blood inorganic phosphorus value of less than 4 mg. percent. However, when the daily supplemental phosphorus intake of a similar group of cows was 6.5 gm. the inorganic phosphorus value was below 4 mg. percent in only a few instances.

Phosphorus Requirements

Van Landingham et al. (1935) found that an average daily intake of 3.8 gm. of phosphorus per 100 lb. of body weight was sufficient to maintain normal inorganic phosphorus in the blood, but that 1.3 gm. daily per 100 lb. of body weight was not sufficient to maintain a normal supply of inorganic phosphorus in the blood of growing dairy animals 6 to 25 months of age.

Henderson and Weakly (1930) fed fairy heifers rations varying in phosphorus content from 0.131 to 0.298 gm. per 100 gm. of ration. They found that rations containing less than 0.20 percent phosphorus would decrease the amount of inorganic phosphorus of the blood. Changes in the dietary level of phosphorus could be detected by changes in blood phosphorus within one week.

Nelson et al. (1955) observed that feeding approximately 4 gm. of phosphorus daily per head during a 21-month period to range beef heifers produced heifers that were 165 lbs. heavier than a similar lot receiving no mineral supplement.

Kleiber et al. (1936) observed that two beef heifers fed a phosphorus-deficient diet containing only 0.13 percent phosphorus ceased to grow after six months on the low-phosphorus regimen, maintained body weight the next year with 0.09 percent phosphorus in the feed, and finally lost weight when fed a diet still lower in phosphorus.

Beeson et al. (1938) observed that a definite phosphorus deficiency was produced in fattening beef steers by feeding a ration containing 0.12 percent phosphorus. The blood plasma phosphorus level dropped from 6.71 to 4.40 mg. percent. Outward symptoms of aphosphorosis were manifested by poor condition, chewing boards, and eating dirt. The addition of 0.66 percent steamed bone meal to the ration increased daily gains from 1.37 to 1.90 lb., caused a 25.3 percent reduction in feed required per 100 lb. of gain, and resulted in maintaining a normal blood phosphorus. The authors concluded that the beef steer requires about 2 gm. of phosphorus daily per 100 lb. of live weight for normal growth and fattening.

Beeson et al. (1941) observed that steers receiving in excess of 2.0 gm. of daily intake of phosphorus per 100 lb. of live weight, did not make any more rapid or efficient gains than those receiving a 2 gm. daily intake of phosphorus. However, steers that received 1.63 gm. daily or less of phosphorus per hundredweight failed to make good gains and utilization of their feed.

Sources of Supplemental Phosphorus

DuToit et al. (1940) classified a number of phosphates as either satisfactory or unsatisfactory for cattle. Those reported as satisfactory were steamed bone meal, degelatinized bone-flour, precipitated lime phosphate (dicalcium phosphate), disodium phosphate and monoammonium phosphate. Defluorinated superphosphate was satisfactory but unpalatable. Listed as unsatisfactory were rock phosphate and super phosphate.

Theiler et al. (1924) fed four phosphorus compounds, wheat bran, bone meal, sodium phosphate, and phosphoric acid. Under their conditions bone meal was the best and cheapest form. It had the added advantage of being palatable. Many other supplements, including ground rock phosphate, were tried but either proved too costly or too difficult of digestion.

Maynard et al. (1936) found that when phosphorus-deficient cattle were fed steamed bone meal, mill-run bran, or cottonseed cake they showed significant increases in blood phosphorus within 38 days.

Wheeler (1945) observed that heifers fed steamed bone meal gained almost 17 percent more than heifers not fed steamed bone meal.

Eckles et al. (1926) observed that cattle can utilize inorganic phosphorus compounds such as tricalcium phosphate and monosodium phosphate.

Turner et al. (1934) observed that either monosodium phosphate and/or disodium phosphate were satisfactory sources of phosphorus for dairy cattle.

Ammerman et al. (1954) used the balance technique to evaluate various phosphorus supplements for yearling steers. Differences in percent phosphorus retained from dicalcium phosphate, steamed bone meal, defluorinated rock phosphate, imported rock phosphate, and colloidal clay were not significant.

Davis et al. (1953) studied the availability of labeled defluorinated phosphate for cattle. They reported that the phosphorus from defluorinated phosphate was as available to calves as was the phosphorus of KH_2PO_4. Approximately 70 percent of 0.04 percent phosphorus from defluorinated phosphate in the ration was absorbed and used by the animal.

Fluorine Toxicity

Peirce (1938a) reviewed chronic fluorine poisoning and reported the syndrome as being reduced appetite, less efficient utilization of feed, exostoses of the long bones and jaw bones, and molars worn to such an extent that in some cases the pulp cavities were exposed. However, serum phosphorus was reported to be unchanged in cows.

Hobbs et al. (1951) conducted metabolism trials with cattle fed from 5 to 100 ppm. of fluorine, and found that fluorine has little, if any, effect on the digestibility of protein, fat, fiber, and nitrogen-free extract, but does lower feed consumption when fed at higher levels.

Peirce (1939) states that the approximate minimum amount of fluorine which, if ingested over a considerable period, will result in the syndrome of chronic fluorosis is about 3 mg. per kg. of body weight each day for the dry cow or sheep.

Hobbs et al. (1953) added sodium fluoride to the rations of Hereford heifers in such amounts as to furnish 0, 100, 200, 300, 600, 900, and 1200 ppm. of fluorine. Symptoms of acute fluorine intoxication developed in those animals receiving 600 ppm. (6.5 mg. fluorine/kg. of body weight) and above. All heifers receiving 600, 900, and 1200 ppm. were sacrificed when they became too stiff and weak to rise.

Schmidt et al. (1954) observed that 2.5 mg. fluorine per kg. of body weight caused only slight exostoses and tooth mottling after a three-year period.

Miscellaneous

Eckles and Gullickson (1927) found that it required at least 20 percent more digestible nutrients when the phosphorus content of the ration is similar to that found in low-phosphorus prairie hay.

Riddell *et al*. (1934) fed Holstein cows a normal ration and a low-phosphorus ration during a digestion trial. The authors state that the digestion coefficients were in close enough agreement to indicate that digestion is not impaired on a phosphorus-deficient ration.

Lindsey *et al*. (1931) conducted phosphorus and calcium balance trialsusing Holstein heifers fed high and low levels of calcium. Where the ratio of calcium to phosphorus was 3.5:1 the retention of phosphorus as percentage of intake was 23.65 for heifers under one year of age. The authors found that the retention ratio of calcium to phosphorus is nearly constant at 2 to 1 irrespective of the ratio in the feed and that a lowered calcium intake will pull down the phosphorus retention.

SHEEP

Phosphorus Deficiency Symptoms

Stewart (1935) studied the effects of phosphorus-deficient diets on the body metabolism, blood, and bones of sheep. The author concluded that phosphorus deficiency is a limiting factor both to body growth and food utilization, that it produces a fall in blood inorganic phosphorus, and that it reduces the total ash content of the long bones eight percent and of other bones by over 25 percent.

Phosphorus Requirements

Beeson et al. (1937) observed that growth was retarded and blood phosphorus lowered to an abnormal level (2 to 3 mg. percent) when lambs received from 0.82 to 1.32 gm. of phosphorus per daily. Phosphorus deficiency, as indicated by low blood phosphorus and slow gains, was produced by feeding a ration containing 0.13 percent phosphorus. The phosphorus requirements of lambs were met by ingesting 2.0 to 2.5 gm. of phosphorus daily as measured by a normal blood phosphorus, rapid gains, and a healthy appearance.

Beeson et al. (1944) observed that rate of growth in lambs is closely correlated with phosphorus intake. The phosphorus in the ration was varied from 0.07 to 0.12 percent and average daily gains ranged from 0.18 to 0.23 lb. daily. There seemed to be no advantage in supplying phosphorus at a level above 0.15 percent of the ration on an air dry basis. The authors state that a low-phosphorus diet does not affect the appetite of lambs as adversely as aphosphorosis in steers. The average food intake of the lambs on the phosphorus-deficient ration was 2.28 lb. daily, while the lambs on the ample-phosphorus diet consumed 2.64 lb. of feed daily. The utilization of feed was affected more acutely than appetite. The low-phosphorus lambs required 20.6 percent more feed to grow and fatten than lambs receiving ample phosphorus.

DuToit et al. (1939) stated that the phosphorus requirements of a 60 lb. lamb is about 1.1 gm. of phosphorus daily.

Gallup and Briggs (1950) conducted phosphorus balance studies in an effort to determine the minimum phosphorus requirements of lambs weighing from 55 to 70 lb. These workers reported negative phosphorus balances with rations which supplied 1.4 to 1.7 gm. of phosphorus daily per 100 lb. of live weight, about an equal number of positive and negative balances with those that supplied from 1.9 to 2.1 gm. of phosphorus, and positive balances in every case with those rations that supplied from 2.4 to 2.9 gm. of phosphorus per head daily.

Ammerman et al. (1955) used sixteen weanling lambs averaging 60 lb. in weight for evaluating dicalcium phosphate, Curacao Island phosphate, soft phosphate with colloidal clay, and defluorinated rock phosphate as sources of phosphorus. Blood serum phosphorus levels, expressed in mg. percent, fell during the depletion period from about 10 to 6 and rose during the supplemental feeding period for the supplements as listed above by average amounts of 2.4, 2.6, 1.3, and 1.3, respectively. These differences were not statistically significant.

Fluorine Toxicity

Shrewbury et al. (1944) observed that the maximum level of fluorine from rock phosphate safely tolerated by lambs as indicated by their rate of gain was 1.5 to 3.1 mg. per kg. of body weight daily. This amounted to from 0.0042 to 0.0064 percent in the total ration. At this level there was some reduction in growth. The authors state that there seemed to be no relation between the level of fluorine intake and plasma inorganic phosphorus.

Hatfield et al. (1942) observed that there were no detrimental effects upon growth and feed consumption by feeding up to 3.0 mg. of fluorine as rock phosphate per day to lambs. All blood values were within the normal range for sheep.

Peirce (1938b) observed that the feed consumption of sheep receiving 160 mg. of fluorine as Nauru rock phosphate and 170 mg. of fluorine as Florida phosphate were 45 and 60 percent, respectively, of that of the controls, and the corresponding percentages of their weights were 55 and 70. These differences did not become significant until the third year of the experiment.

Hobbs et al. (1954) stated that wether lambs receiving rations with 200 ppm. fluorine added as NaF for 5 months showed an indication of a slight decrease in feed consumption. The authors stated that the fluorine content of the feed, up to 200 ppm., did not affect the phosphorus level of blood serum of lambs.

Although steamed bone meal is the phosphorus supplement ordinarily used in beef cattle rations there are other supplements which have been used. The availability of phosphorus from the various inorganic phosphates has not been comparatively rated for cattle. The usual measures of the state of phosphorus nutrition in the animal body are weight gain and inorganic phosphorus content of the blood. The data reported in this thesis are the results obtained in an experiment which was designed to (1) determine the most efficient measure of plane of phosphorus nutrition, (2) determine the optimum level of phosphorus intake by steers for evaluating the availability of phosphorus, and (3) comparatively evaluate selected inorganic phosphates as a source of phosphorus for ruminants.

EXPERIMENT I

RESPONSE OF STEERS FED DIFFERENT LEVELS OF PHOSPHORUS

In order to study the availability of phosphorus in various supplements it is necessary to determine a suitable level of phosphorus intake and to know the value of various measures of the state of phosphorus nutrition in the animal body. This experiment was designed to furnish data relating to the above factors.

PART 1

Experimental Procedure

Nine grade Hereford steer calves weighing approximately 390 lb., selected from the college experimental herd at Lake Carl Blackwell range area, were used in this experiment. On arrival at the experimental steer shed at Stillwater, the calves were confined to dirt-floored pens approximately 30 by 100 feet in size. Water and the basal ration to be described later were given ad libitum from December 27, 1954, to January 15, 1955. The steers were moved to the metabolism room and confined in three concrete-paved pens approximately 10 by 15 feet in size. Here they were individually fed the basal ration (Ration 1) of the composition shown in table 1. From January 15 to February 15 the intake of all steers was limited to the amount consumed by the steer that consumed the least. The feeding system was changed February 15 and after that date each steer was fed as much as he would consume in two daily feeding periods of approximately one hour each.

The experimental rations (table 1) were formulated in such a manner that each had the same calcium to phosphorus ratio. The percentages of phosphorus in rations 1, 2, and 3 were 0.094, 0.144, and 0.194, respectively. From the initiation of the experiment until April 21, 1955, vitamin A and D oil was added to the rations in such amounts as would furnish 2724 I.U. of vitamin A, and 545 I.U. of vitamin D per lb. of feed. On April 21, 1955, micratized vitamin A and D supplement replaced the oil supplement in all rations.

On March 3, 1955, the animals were allotted to one of the three treatments on the basis of weight and plasma inorganic phosphorus. Water was available at all times except for the two daily feeding periods, and for a twelve-hour shrinking period prior to each weighing and bleeding. Body weights, feed consumption, and plasma inorganic phosphorus were determined at approximately 14-day intervals. X-rays of the ulna and metacarpal bone of the right leg of each animal were taken once monthly in order to measure the effect of level of phosphorus intake on the width of the epiphyseal plate.

Phosphorus determinations were made by a modification of the method of Fiske and Subbarow (1925). The data were analyzed statistically by the analysis of variance method of Snedecor (1946).

Results

Weight Gain

The weight gain data of the 104-day feeding test are presented in table 2. The average gain of the steers fed ration 3 (basal plus 0.10 percent supplemental phosphorus) was 12 lb. greater than that of the steers fed ration 2 (basal plus 0.05 percent supplemental phosphorus). The average gain of the steers fed ration 2 was 107 lb. greater than

Table 1. Composition of Experimental Rations
(pounds)

Ingredients	Ration 1	Ration 2	Ration 3
Cottonseed hulls	36.1	36.1	36.1
Dried beet pulp	27.2	27.2	27.2
Dehydrated alfalfa meal	9.1	9.1	9.1
Urea (two-sixty-two)	0.1	0.1	0.1
Cerelose	18.0	18.0	18.0
Corn gluten meal	9.1	9.1	9.1
Vit. A & D supplement	0.2	0.2	0.2
NaCl	0.2	0.2	0.2
NaH_2PO_4		0.4	0.8
$CaCO_3$		0.4	0.9
P from monsodium phosphate (%)	0.0	0.05	0.1
P from basal ration (%)	0.09	0.09	0.09

Table 2. Average Weight Gain of Steers
(pounds)

Period ending	Ration 1	Ration 2	Ration 3
March 17, 1955*	16	23	34
March 31	1	15	11
April 14	4	19	16
April 28	12	20	23
May 12	-8	14	25
May 26	5	36	21
June 15	-9	1	10
Av. total gain	21	128	140

*Average initial weights on March 3 were 413, 411, and 410 lb. for the steers fed rations 1, 2, and 3, respectively.

that of the steers fed ration 1 (basal). The multiple range test (Duncan, 1955) showed that the gains of the steers fed either ration 2 or 3 were significantly greater (P of less than .01) than those of steers fed ration 1. The animals fed ration 3 gained slightly more than the animals fed ration 2; these differences were not significant.

Plasma Inorganic Phosphorus

The plasma inorganic phosphorus values are shown in table 3. At the end of the test the steers fed rations 1, 2, and 3 had average plasma inorganic phosphorus values of 2.9, 5.4, and 6.1 mg., respectively. The animals fed the basal ration showed a decrease of 1.0 mg. percent in plasma inorganic phosphorus level, while those receiving 0.05 and 0.10 percent supplemental phosphorus, respectively, gained 1.6 and 2.5 mg. percent. The multiple range test showed that the plasma inorganic phosphorus values for the steers fed either ration 2 or 3 were significantly greater (P of less than .01) than those of the steers fed ration 1. The plasma inorganic phosphorus values of the steers fed ration 3 were not significantly different from those of the steers fed ration 2.

Feed Consumption

The results obtained in Part 1 are shown in table 4. The steers fed ration 1, with only temporary exceptions, consumed less feed as the experiment progressed, and in the last two-week period had an average daily feed consumption of 4.72 lb. The steers fed rations 2 and 3 showed a gradual increase in daily feed consumption; the intake of both lots plateaued at approximately 10 lb. daily during the last three periods. These differences were not significant statistically. The feed required per 100 lb. of gain was 3,000, 738, and 675 for the steers fed rations 1, 2, and 3, respectively.

Table 3. Average Plasma Inorganic Phosphorus Values
(mg./100 ml. plasma)

Date	Ration 1	Ration 2	Ration 3
March 3, 1955	3.87	3.81	3.64
March 17	3.27	2.92	5.29
March 31	3.23	6.33	5.00
April 5	3.16	5.04	5.29
April 14	2.88	4.89	7.81
April 29	3.03	6.11	8.69
May 12	2.71	5.55	6.56
May 26	3.04	6.15	7.49
June 15	2.87	5.43	6.09
Av. total gain	-1.00	1.62	2.45

Table 4. Average Daily Feed Consumption
(pounds)

Period ending	Ration 1	Ration 2	Ration 3
March 17, 1955	8.74	8.70	8.74
March 31	7.31	8.05	8.17
April 14	8.90	9.93	9.93
April 28	6.26	9.43	9.43
May 12	4.94	10.00	10.00
May 28	5.31	10.02	10.07
June 15	4.72	10.00	10.00

Discussion

The steers fed rations 2 and 3 made considerably greater gains, 128 and 140 lb., respectively, in the 104-day feeding period than those fed ration 1. The steers fed ration 1 gained an average of 33 lb. during the first 56 days of the experimental period, then lost 12 lb. during the next 48 days, resulting in a total gain of 21 lb. for the entire period. The differences in gains were statistically significant within 56 days, indicating that a longer experimental period may not be necessary.

The plasma inorganic phosphorus values of the steers were significantly different (P of less than .05) after only 15 days on the experimental rations, and approached significance at the 1 percent probability level 13 days later. Six days later it was observed that the plasma inorganic phosphorus values for the steers fed rations 2 and 3 had crossed. Chemical analysis of the rations being fed indicated that the rations had inadvertently been switched. Fresh feed mixtures were prepared and fed to the steers, and 11 days later the plasma inorganic phosphorus values had crossed back to their original relationship, and were significantly different (P of less than .01). A positive correlation of 0.83 was observed between plasma inorganic phosphorus and weight gain. In this experiment a change of 0.05 percent phosphorus in the ration was reflected in a statistically significant difference in plasma inorganic phosphorus within one week, but approximately six weeks were required for the effect of phosphorus supplementation to be shown in the weight gain. The sensitivity of feed consumption was similar to that of weight gain. It is possible that the loss of weight observed when cattle are fed a phosphorus-deficient ration is a secondary effect caused by decreased feed consumption. This is in agreement with Black <u>et</u> <u>al</u>.

(1943) and Theiler and Green (1932) who observed that a fall in blood plasma phosphorus preceded any outward signs of bovine aphosphorosis.

Satisfactory measurements of the width of the epiphyseal-diaphyseal plate from X-rays of the ulna and metacarpal were not obtained, due to the apparent early closure of this plate. However, enlarged joints were observable in all X-rays of the steers.

It is of interest to note that during the early part of the experiment the steers fed rations 1, 2, and 3 consumed approximately 0.9, 1.4, and 1.8 gm. of phosphorus, respectively, per 100 lb. of body weight daily. During the terminal period of the experiment the same steers consumed 0.5, 1.2, and 1.6 gm. of phosphorus daily per 100 lb. of body weight. There was only a small difference between the responses of steers fed rations 2 and 3. At the levels fed, phosphorus had a curvilinear effect on plasma inorganic phosphorus, feed consumption, and weight gain.

PART 2

This phase of the experiment was designed to secure additional information on the value of various measures of the state of phosphorus nutrition in the animal body, and the most desirable level of phosphorus intake at which to study the availability of phosphorus in various phosphorus supplements fed to steers.

Experimental Procedure

Nine grade hereford steer calves weighing approximately 350 lb. were used in this experiment. The steers were fed the basal ration (ration 1), composition shown in table 5, for a 53-day depletion period. At the termination of period 1, the animals were allotted to one of three treatments on the basis of weight, for an 89-day experimental period (period 2). No X-rays were taken during the course of this experiment; all other details were as in Part 1.

Results

Weight Gain

The results obtained during Part 2 are shown in table 6. The average gain of the steers fed ration 3 (basal plus 0.08 percent supplemental phosphorus) was 22 lb. greater than that of the steers fed ration 2 (basal plus 0.04 percent supplemental phosphorus). The average gain of the steers fed ration 2 was 48 lb. greater than that of the steers fed ration 1 (basal). The multiple range test (Duncan, 1955) showed that the gains of the steers fed either ration 2 or 3 were significantly greater (P of less than .05) than those of steers fed ration 1. The animals fed ration 3 gained 24 lb. more than the animals fed ration 2; these differences were not significant. As the level of supplemental phosphorus was increased from 0.0 to 0.08 percent of the total ration there was a

Table 5. Composition of Experimental Rations
(pounds)

Ingredients	Ration 1	Ration 2	Ration 3
Cottonseed hulls	36.3	36.3	36.3
Dried beet pulp	27.2	27.2	27.2
Dehydrated alfalfa meal	9.1	9.1	9.1
Urea (two-sixty-two)	1.0	1.0	1.0
Cerelose	22.7	22.7	22.7
Corn gluten meal	3.7	3.7	3.7
Vit. A & D supplement	0.1	0.1	0.1
NaCl	0.5	0.5	0.5
NaH_2PO_4		0.17	0.34
$CaCO_3$			0.41
P from monsodium phosphate (%)		0.04	0.08
P from basal ration (%)	0.07	0.07	0.07

Table 6. Average Weight Gain of Steers
(pounds)

Period ending	Ration 1	Ration 2	Ration 3
January 7, 1956*	10	16	10
January 21	5	6	12
February 4	3	4	15
February 18	10	25	21
March 3	1	9	17
March 17	1	20	18
March 31	0	0	9
Av. total gain	30	80	102

*Average initial weights on December 23 were 353, 358, and 365 lb. for the steers fed rations 1, 2, and 3, respectively.

significant linear effect (t of less than .05) of the inorganic phosphorus on increasing body weight gain. At the levels fed, 0.1 percent supplemental phosphorus added to the ration resulted in 8.51 ∓ 7.77 lb. of body weight gain, in this experiment.

Plasma Inorganic Phosphorus

The plasma inorganic phosphorus values are shown in table 7. At the end of the test the steers fed rations 1, 2, and 3 had average plasma inorganic phosphorus values of 2.80, 4.17, and 5.88 mg. percent, respectively. The animals fed the basal ration and those receiving 0.04 percent supplemental phosphorus showed a decrease of 1.41 and 0.14 mg. percent in plasma inorganic phosphorus level, respectively; those receiving 0.08 percent supplemental phosphorus gained 0.84 mg. percent. The multiple range test (Duncan, 1955) showed that plasma inorganic phosphorus levels of the steers fed either ration 2 or 3 were significantly greater (P of less than .05) than those of the steers fed ration 1. The plasma inorganic phosphorus values of the steers fed ration 3 were not significantly different from those of the steers fed ration 2. As the level of supplemental phosphorus was increased from 0.0 to 0.08 percent of the total ration there was a significant linear effect (t of less than .02) of the inorganic phosphorus on increasing the level of plasma inorganic phosphorus. At the levels fed, 0.1 percent supplemental phosphorus increased plasma inorganic phosphorus 2.817 ∓ 2.185 mg. percent.

Feed Consumption

The results obtained during part 2 are shown in table 8. The average gain in daily feed consumption was -1.34, 2.98, and 5.01 for rations 1, 2, and 3, respectively. The multiple range showed that the

Table 7. Average Plasma Inorganic Phosphorus Values
(mg./100 ml. plasma)

Date	Ration 1	Ration 2	Ration 3
December 23, 1955	4.21	4.31	5.04
January 7, 1956	3.91	5.53	5.65
January 21	3.49	5.82	7.09
February 4	3.52	6.28	6.21
February 18	3.23	4.73	5.87
March 3	2.89	4.91	6.36
March 17	2.89	4.44	6.52
March 31	2.80	4.17	5.88
Av. total gain	-1.41	-0.14	0.84

Table 8. Average Daily Feed Consumption
(pounds)

Period ending	Ration 1	Ration 2	Ration 3
January 6, 1956	6.7	6.7	7.3
January 21	5.3	6.5	7.5
February 4	5.5	6.9	8.2
February 18	5.9	7.5	8.9
March 3	5.6	8.2	9.6
March 17	5.5	9.2	10.3
March 31	5.4	9.7	12.3
Av. daily feed consumption	5.6	7.9	9.2

daily gain in feed consumption was significantly greater (P of less than .01) for the steers fed rations 2 or 3 than those of the steers fed ration 1. As the level of supplemental phosphorus was increased from 0.0 to 0.08 percent of the total ration there was a significant linear effect (t of less than .01) of the inorganic phosphorus on increasing daily feed consumption. At the levels fed, 0.1 percent supplemental phosphorus added to the ration resulted in 7.95 1.77 lb. gain in daily feed consumption. The feed required per 100 lb. of gain was 4980, 2648, and 2394 for the steers fed rations 1, 2, and 3, respectively.

Discussion

The steers fed rations 2 and 3 made considerably greater gains, 45 and 70 lb., respectively, in the 89-day feeding period, than those fed ration 1. The steers fed ration 1 gained 28 lb. during the first 47 days of the experimental period, and 2 lb. during the next 42 days. This was a total gain of 30 lb. in the entire period. The gains of the steers fed either ration 2 or 3 were significantly greater (P of less than .05) than those of the steers fed ration 1. As the level of supplemental phosphorus was increased from 0.0 to 0.08 percent of the total ration, a significant linear effect (t of less than .05) on body weight gain was observed.

The plasma inorganic phosphorus levels of the steers fed either ration 2 or 3 were significantly greater (P of less than .05) than those of the steers fed ration 1. However, the plasma inorganic phosphorus values of the steers fed ration 3 were not different statistically at the 5 percent level of probability from those of the steers fed ration 2. The percent phosphorus in the ration had a significant linear effect, at the 0.02 probability level, on level of plasma inorganic phosphorus.

There was a significant linear effect (t of less than .01) of phosphorus intake on feed consumption. The steers fed ration 1 required 88 percent more feed per 100 lb. of gain, and consumed 39 percent less feed, as compared to the steers fed ration 2. The steers fed ration 2 required 11 percent more feed per 100 lb. of gain, and consumed 15 percent less feed, as compared to the steers fed ration 3.

Fifteen-hundredths percent phosphorus in the total ration appears to be the most suitable level at which to study the availability of phosphorus in various phosphorus supplements to steers. Changes in the level of phosphorus nutrition of steers are detectable by changes in the inorganic phosphorus content of the plasma within approximately one week. However, it requires approximately 30 days after changes in the level of phosphorus nutrition are detectable in plasma inorganic phosphorus before they have any significant effect on feed consumption or body weight gain.

SUMMARY

Two feeding trials, each involving 9 grade Hereford steers, were conducted to secure information as to the value of various measures of the state of phosphorus nutrition, and the most desirable level of phosphorus in the ration at which to study phosphorus availability. Criteria of response were plasma inorganic phosphorus, feed consumption, body weight, and feed efficiency.

The results show that after partial depletion changes in the state of phosphorus nutrition were reflected by changes in plasma inorganic phosphorus within 7 days, and by changes in feed consumption or body weight within 30 to 60 additional days. At levels of phosphorus in the total ration ranging from 0.07 to 0.15 percent, there was a significant linear effect on all criteria used. A suitable level of phosphorus intake at which to evaluate phosphorus supplements with steers is apparently 0.15 percent of the total ration.

EXPERIMENT II

A COMPARISON OF DICALCIUM PHOSPHATE AND COLLOIDAL CLAY AS SOURCES OF PHOSPHORUS FOR BEEF HEIFERS

Experimental Procedure

The experiment was divided into three consecutive periods, period 1 being a depletion period for all animals. During period 1 the experimental animals, 12 Angus x Hereford and 12 grade Hereford heifers, were self-fed the basal ration of the composition shown in table 9. At the end of the 68-day depletion period, the animals were divided into three groups, each having four crossbred and four Hereford animals.

During period 2, one group of heifers continued to receive the basal diet (ration 1), another group received the basal plus 0.05 percent supplemental phosphorus supplied by colloidal clay (ration 2), while the third group received the basal plus 0.05 percent supplemental phosphorus supplied by dicalcium phosphate (ration 3). All lots were group-fed from self-feeders during the 98-day period. Weights were taken at 14-day intervals. A 12-hour shrink period preceded each weighing during which time the animals were away from feed and water. The self-feeders were cleaned at monthly intervals, and feed consumption was calculated at this time.

The four crossbred heifers in each lot were slaughtered at the end of period 2 and bone samples from the cannon and mandible were taken for determination of ash. A one-inch section from the middle of the cannon bone was removed for measurement of thickness of the ring; measurements

Table 9. Composition of Experimental Rations
(pounds)

Ingredients	Ration 1	Ration 2	Ration 3
Cottonseed hulls	36.3	36.3	36.3
Dried beet pulp	27.2	27.2	27.2
Dehydrated alfalfa meal	9.1	9.1	9.1
Cerelose	18.0	18.0	18.0
Corn gluten meal	9.1	9.1	9.1
Urea (two-sixty-two)	0.1	0.1	0.1
A & D supplement[a]	0.2	0.2	0.2
Dicalcium phosphate			0.27
Colloidal clay		0.67	
Calcium carbonate		0.09	0.14
P from supplement	0.0	0.05	0.05
P from basal	0.09	0.09	0.09

[a]Contributed the following per pound of total ration: vitamin A 2724 I.U.; vitamin D 340 I.U.

were taken at several spots on both ends and these values averaged for a thickness value.

At the end of period 2, there were four Hereford heifers remaining in each lot and all of these were continued on feed for an additional 80 days, period 3. The group of animals which had received the basal ration (ration 1) during period 2 were fed the ration containing dicalcium phosphate (ration 3) during period 3. The other groups were continued on their respective rations. All other details remained the same.

Blood samples for plasma inorganic phosphorus determinations were obtained by jugular puncture at 14-day intervals. Phosphorus determinations in the plasma and feeds were made colorimetrically by modification of the method of Fiske and Subbarow (1925). The data were analyzed statistically by analysis of variance (Snedecor, 1946) and multiple range test (Duncan, 1955).

Results

Weight Gain

The results obtained during period 2 are shown in table 10.

During period 2, the animals receiving dicalcium phosphate gained 91 lb. more than those receiving an equal amount of phosphorus from colloidal clay and 107 lb. more than those receiving the unsupplemented diet; the differences were significant at the one percent level of probability. The group which received colloidal clay gained only 16 lb. more than the negative control group.

The gains of heifers during period 3 are shown in table 11.

During period 3, the heifers which were changed from the basal ration to the one supplemented with dicalcium phosphate gained 0.87 lb. daily, an 18 percent increase over their performance during the 98 days they received the basal ration. There was no great change in the performance of the animals maintained on dicalcium phosphate, but those maintained on colloidal clay gained at a much slower rate. These latter heifers had trouble in walking and appeared unwilling to move. A definite creaking was heard when these animals walked.

Feed Consumption

The results obtained during the repletion phase are shown in table 12.

The average daily feed consumed during period 2 was 9.5, 12.0, and 14.7 lb. for rations 1, 2, and 3, respectively. The feed required per 100 lb. of gain was 2912, 2138, and 990 for the heifers fed rations 1, 2, and 3, respectively. Early in the experiment the appetites of the heifers fed the basal ration appeared to be reduced and remained low for the entire period. Toward the end of this period, the animals consuming the ration supplemented with colloidal clay definitely had reduced appetites.

Table 10. Average Weight Gain of Heifers
Period 2
(pounds)

Period ending	Ration 1	Ration 2	Ration 3
March 20*	16	23	46
April 2	2	14	17
April 17	16	16	34
April 30	0	0	10
May 14	6	5	18
May 28	2	7	15
June 11	-3	-10	6
Av. total gain	39	55	146

*Average initial weights on March 5 were 464, 468, and 468 lb. for the heifers fed rations 1, 2, and 3, respectively.

Table 11. Average Weight Gain of Hereford Heifers
Period 3
(pounds)

Period ending	Ration 3 (recovery)	Ration 2	Ration 3
July 3*	18	0	9
July 15	0	-2	8
July 29	28	4	28
August 16	15	11	24
August 30	10	5	8
Av. total gain	71	18	77

*Average initial weights on June 11 were 482, 491, and 586 lb. for the heifers fed rations 1, 2, and 3, respectively.

Table 12. Average Daily Feed Consumption
Period 2
(pounds)

Period ending	Ration 1	Ration 2	Ration 3
March 20, 1955	10.8	13.0	15.6
April 17	9.5	12.1	14.9
May 11	9.9	12.5	14.7
June 11	9.1	11.6	14.7

The results obtained during period 3 are shown in table 13.

During period 3, the animals which had received the basal diet during period 2 increased their daily feed consumption from 9.5 to 11.3 lb. The group receiving colloidal clay, however, decreased their feed consumption from 12.0 to 8.9 lb. daily, while the animals continued on the dicalcium phosphate supplemented rations increased their daily consumption from 14.7 to 14.9 lb. The feed required per 100 lb. of gain was 1265, 3942, and 1421 for the heifers fed rations 1, 2, and 3, respectively.

Plasma Inorganic Phosphorus

The plasma phosphorus data obtained during period 2 are shown in table 14. Data obtained with the Hereford heifers in period 3 are shown in table 15.

At the end of period 1, the heifers allotted to rations 1, 2, and 3 had average plasma inorganic phosphorus values of 2.85, 2.66, and 2.48 mg. percent, respectively. At the end of period 2, the basal-fed group had an average value of 2.0 mg. percent; those fed ration 2 (colloidal clay) and ration 3 (dicalcium phosphate) had values of 2.78 and 3.67, respectively. The animals receiving dicalcium phosphate had values which

Table 13. Average Daily Feed Consumption
Period 3
(pounds)

Period ending	Ration 3 (recovery)	Ration 2	Ration 3
July 2, 1955	10.3	11.8	13.6
July 29	11.9	7.9	16.0
August 30	12.0	8.3	15.9

Table 14. Plasma Inorganic Phosphorus
Period 2
(mg. P/100 ml. plasma)

Date	Ration 1	Ration 2	Ration 3
March 2, 1955	2.85	2.66	2.48
April 17	2.98	3.53	4.60
May 19	2.31	3.17	4.18
June 11	2.04	2.78	3.67
Av. total gain	-0.81	0.12	1.19

Table 15. Plasma Inorganic Phosphorus
Period 3
(mg. P/100 ml. plasma)

Date	Ration 1	Ration 2	Ration 3
June 11, 1955	1.95	2.40	3.58
June 21	2.61	2.77	
July 3	2.85	2.89	
July 15	2.88	2.78	3.85
July 29	3.36	2.59	4.00
August 16	2.95	2.63	3.55
August 30	2.71	2.38	3.43
Av. total gain	0.76	-0.02	-0.15

were significantly higher (P of less than .01) than those of the groups receiving colloidal clay or the unsupplemented ration. At the 5 percent probability level, the differences between the plasma inorganic phosphorus level of the basal- and colloidal clay-fed group were not significant.

During period 3, the animals which had been fed the basal ration during period 2 showed a gain of 0.8 mg. percent when they were changed to the ration supplemented with dicalcium phosphate. There were practically no changes in the other two groups.

Bone Data

The average ash contents of the cannon bones on a fat- and moisture-free basis were, in percent, 55.5, 57.1, and 59.2 for the heifers fed rations 1, 2, and 3, respectively. The heifers fed ration 3 had significantly more (P less than .01) ash in their cannon bones than the heifers fed ration 1.

The ash contents of the mandibles were in percent, 61.40, 62.5, and 64.9 for rations 1, 2, and 3, respectively. In the case of ration 3 this value was significantly greater than those of either ration 1 or 2 (P of less than .01).

The walls of the cannon diaphyses (average of six measurements) were 2.79, 3.03, and 2.81 mm. for rations 1, 2, and 3, respectively. The diaphyseal wall was significantly thicker (P of less than .01) for the heifers fed ration 2 as compared to those fed rations 1 and 3.

Discussion

If the growth response from 0.05 percent supplemental phosphorus supplied by dicalcium phosphate were given an arbitrary value of 100, it is found that value of the phosphorus of colloidal clay was only 17. When plasma inorganic phosphorus was the criteria, the value of phosphorus of colloidal clay was 45. This is in agreement with the results observed by Grau and Zweigert (1953) who reported that the growth rate of chicks was not benefited by the addition of colloidal clay to their rations and Miller and Joukousky (1953) who stated that colloidal clay had a value of less than 50 percent of the value of other minerals tested.

The heifers receiving colloidal clay had significantly less ash in their cannon bones and mandibles than those fed dicalcium phosphate; however, the heifers fed colloidal clay had thicker diaphyseal wall of the cannon bones.

There was considerable difference in the general appearance of the heifers fed the three rations. Those fed ration 3 (dicalcium phosphate) gained an average of 1.48 lb. daily and presented a normal appearance. The hair coats of the heifers fed ration 1(basal) appeared slightly rough, a slight enlargement of the joints had occurred, and one heifer evidenced lameness. The heifers fed ration 2 (colloidal clay) were less thrifty in appearance than the other heifers. Their hair coats were rough and they were somewhat emaciated. These heifers had enlarged joints and two of them walked with difficulty. The heifers fed rations 1 and 2 had a definite pica syndrome as evidenced by chewing on wood, wire, or other foreign material. These heifers were also coprophagous.

At the termination of period 3 there were noticeable changes in the general appearance of the heifers. Those fed the recovery ration, that is, fed the ration containing dicalcium phosphate during period 3 after having been fed the basal ration during period 2, now evidenced only occasional signs of pica and coprophagy. However, one heifer was still definitely creepy. Two of the heifers fed ration 2 showed considerable stiffness of the legs, their hooves were elongated, and they walked only with difficulty. Pica and coprophagy were quite evident in the heifers fed this ration. One heifer which had been fed the recovery ration and two heifers from the colloidal clay lot were slaughtered; their physical condition was such as to make recovery doubtful. Exostoses were observed on the cannon bones of the heifers fed ration 2, and their teeth exhibited signs of wear. However, no signs of tooth mottling were observed. The heifers fed ration 3 appeared healthy and thrifty. The nine heifers remaining in the experiment were returned to the college experimental range. It was necessary to slaughter one of the remaining colloidal clay heifers within two weeks, as she became unable to walk. The remaining colloidal clay heifer was slaughtered after 57 days on grass because she became extremely emaciated. During this period she lost 123 lb. The remaining heifers were slaughtered after approximately three months on grass. Enlarged joints were the only observed abnormality.

The fluorine content of the colloidal clay supplement was 0.97 percent and thus the ration contained 642 ppm. of fluorine. Mitchell and Edman (1952) reported that about 100 ppm. of fluorine supplied in rock phosphate was on the border line of toxicity in cattle. Hobbs et al. (1953) observed symptoms of acute fluorine intoxication in Hereford heifers with 600 ppm. of fluorine in the ration. It is possible that the response of the heifers fed ration 2 was due to a combination of phosphorus deficiency and fluorine toxicity.

Summary

Three groups of 8 beef heifers each were used to determine the relative value of soft phosphate with colloidal clay and dicalcium phosphate as inorganic phosphorus supplements for growing beef heifers. One group was fed a low-phosphorus basal ration, 0.09 percent phosphorus, and the other two groups were fed the basal ration supplemented with 0.05 percent phosphorus as colloidal clay and as dicalcium phosphate. Criteria of response were weight gains, plasma inorganic phosphorus, and ash content of cannon bone and mandible. The feeding of colloidal clay resulted in a significantly lower weight gain, plasma inorganic phosphorus, and ash content of cannon bone or mandible than when dicalcium phosphate was fed. Heifers fed colloidal clay exhibited pica, coprophagy and walked with difficulty. Heifers fed dicalcium phosphate were apparently normal.

EXPERIMENT III

A COMPARISON OF DICALCIUM PHOSPHATE, STEAMED BONE MEAL, AND CURA-PHOS AS SOURCES OF PHOSPHORUS FOR BEEF HEIFERS

It has been known for a considerable period of time that the addition to ruminant rations of various phosphatic materials often resulted in improved daily gains and prevented bone abnormalities. However, there is a dearth of data on the comparative value of steamed bone meal, Curacao Island phosphate, and dicalcium phosphate. This experiment was designed to investigate the value of these sources of phosphorus.

Experimental Procedure

The experiment was divided into two consecutive periods, period 1 being a depletion period for all animals and period 2 the actual test of the value of different phosphorus supplements. During period 1 the experimental animals, 31 grade Hereford heifers, were self-fed the basal ration of the composition shown in table 16. At the end of the 43-day depletion period, the animals were divided at random into four groups.

During period 2, one group of heifers continued to receive the basal diet (ration 1); another group received the basal plus 0.08 percent supplemental phosphorus supplied by steamed bone meal (ration 2); the third group received the basal plus 0.08 percent supplemental phosphorus

Table 16. Composition of Experimental Rations (pounds)

Ingredients	Ration 1	Ration 2	Ration 3	Ration 4
Cottonseed hulls	36.3	36.3	36.3	36.3
Dried beet pulp	27.2	27.2	27.2	27.2
Dehydrated alfalfa meal	9.1	9.1	9.1	9.1
Cerelose	22.7	22.7	22.7	22.7
Corn gluten meal	3.7	3.7	3.7	3.7
Urea (two-sixty-two)	1.0	1.0	1.0	1.0
A & D supplement[a]	0.1	0.1	0.1	0.1
Steamed bone meal		0.6		
Curacao Island phosphate			0.6	
Dicalcium phosphate				0.4
Calcium carbonate		0.01		0.06
P from supplement		0.08	0.08	0.08
P from basal	0.07	0.07	0.07	0.07

[a]Contributed the following per pound of total ration: vitamin A 2724 I.U.; vitamin D 340 I.U.

supplied by Cura-Phos* (ration 3); and the fourth group received the basal plus 0.08 percent supplemental phosphorus supplied by dicalcium phosphate (ration 4). All lots were group-fed from self-feeders during the 89-day period. Weights were taken at 14-day intervals. A 12-hour shrink period preceded each weighing during which time the animals were away from feed and water. The self-feeders were cleaned at monthly intervals, with feed consumption data being calculated at this time.

Blood samples for plasma phosphorus determinations were obtained by jugular puncture at 14-day intervals. Phosphorus determinations in the plasma and feeds were made colorimetrically by modification of the method of Fiske and Subbarow (1925). The data were analyzed statistically by analysis of variance (Snedecor, 1946) and multiple range test (Duncan, 1955).

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*Cura-Phos is the trade name for Curacao Island Phosphate.

Results

Weight Gain

The results obtained during period 2 are shown in table 17. The heifers receiving the basal ration gained significantly less (P of less than .01) than those receiving supplemental phosphorus supplied by steamed bone meal, Cura-Phos, or dicalcium phosphate. During the 89-day feeding period, the heifers fed rations 1, 2, 3, and 4 gained 0.16, 1.32, 1.52, and 1.33 lb. daily, respectively.

Plasma Inorganic Phosphorus

The plasma phosphorus data obtained during period 2 are shown in table 18. At the end of period 1, the heifers allotted to rations 1, 2, 3, and 4 had average plasma inorganic phosphorus values of 3.29, 2.81, 3.34, and 3.51 mg. percent, respectively. At the end of period 2, the basal-fed group had an average value of 2.36 mg. percent; those fed ration 2 (steamed bone meal), ration 3 (Cura-Phos), and ration 4 (dicalcium phosphate) had values of 4.46, 4.28, and 3.88 mg. percent, respectively. The heifers fed the basal ration gained significantly less (P of less than .01) in plasma inorganic phosphorus as compared to the gain of the heifers fed the supplemented ration. There were no significant differences in the gain in plasma inorganic phosphorus of the heifers fed rations 2, 3, and 4.

Feed Consumption

The results obtained during period 2 are shown in table 19. The average daily feed consumption during period 2 was 11.1, 16.2, 16.1, and 15.6 for rations 1, 2, 3, and 4, respectively. The feed consumption of the heifers fed the basal ration showed a consistent decline during

Table 17. Average Weight Gain of Heifers
Period 2
(pounds)

Period ending	Ration 1	Ration 2*	Ration 3	Ration 4
January 7**	6	-1	-1	4
January 21	11	29	34	24
February 4	2	29	22	21
February 18	6	17	23	25
March 3	4	18	17	28
March 17	2	17	22	12
March 31	-17	8	18	4
Av. total gain	14	117	135	118

*Ration 2 was fed to 7 heifers, all other rations were fed to lots of 8 heifers each.
**Average initial weights on December 23 were 477, 467, 444, and 443 lb. for the heifers fed rations 1, 2, 3, and 4, respectively.

Table 18. Plasma Inorganic Phosphorus
Period 2
(mg. P/100 ml. plasma)

Date	Ration 1	Ration 2	Ration 3	Ration 4
December 23, 1955	3.29	2.81	3.35	3.52
January 7, 1956	3.49	4.59	4.83	4.84
January 21	2.87	4.02	5.20	4.74
February 4	2.42	4.82	5.25	4.65
February 18	2.33	4.83	4.18	5.02
March 3	2.69	5.01	4.24	4.58
March 17	2.64	4.74	4.66	4.33
March 31	2.36	4.46	4.28	3.88
Av. total gain	-0.93	1.65	0.94	0.37

Table 19. Average Daily Feed Consumption
Period 2
(pounds)

Period ending	Ration 1	Ration 2	Ration 3	Ration 4
January 21, 1956	13.2	15.1	13.6	13.5
February 18	12.1	17.1	15.7	15.5
March 17	10.2	16.2	17.5	16.9
March 31	8.2	15.8	17.4	15.9
Av. daily feed consumption	11.1	16.2	16.1	15.6

period 2, this amounted to 4.9 lb. daily, when final feed consumption was compared to initial. During this same period the heifers fed rations 2, 3, and 4 increased 0.7, 3.8, and 2.4 lb. in daily feed consumption, respectively. The feed required per 100 lb. of gain was 7078, 1076, 1061, and 1176 lb. for the heifers fed rations 1, 2, 3, and 4, respectively.

Discussion

If the growth response to added dicalcium phosphate were arbitrarily assigned the value of 100, the values of steamed bone meal and Cura-Phos, respectively, were 99 and 115. If plasma inorganic phosphorus were used as the criteria the values were 198 and 144. The heifers fed the basal ration gained significantly less (P of less than .01) in plasma inorganic phosphorus as compared to the gain of the heifers fed the supplemented rations. There were no significant differences in the gain in plasma inorganic phosphorus of the heifers fed rations 2, 3, and 4. The weight gains and feed efficiencies were almost identical for the heifers fed supplemented rations. However, heifers fed the basal ration gained approximately 11 percent as much as those fed the supplemented rations, while consuming 70 percent as much feed. The heifers fed the basal ration were noticeably thinner than the heifers fed the supplemented rations. No signs of abnormal appetite or bone abnormalities were observed. From the results of this experiment, the availability of phosphorus from steamed bone meal, Cura-Phos, and dicalcium phosphate appears to be approximately equal when fed to Hereford heifers.

Fluoride toxicity does not appear to be a problem in the addition of Cura-Phos to cattle rations. In this experiment Cura-Phos furnished 0.08 percent phosphorus in the total ration, the fluorine content of the ration was 275 ppm., and no deleterious effects were observed. Hobbs et al. (1954) reported that heifers ingesting rations containing 200 and 300 ppm. of added fluorine showed a significant decrease in feed consumption within 12 months from the start of the test. If this experiment had been of longer duration different results might have been obtained.

Summary

Four groups of 8 grade Hereford heifers each were used to determine the relative values of steamed bone meal, Cura-Phos, and dicalcium phosphate as inorganic phosphorus sources for cattle. One group was fed the basal ration, 0.07 percent phosphorus, the other three groups were fed the basal ration supplemented with 0.08 percent phosphorus as steamed bone meal, Cura-Phos, or dicalcium phosphate. Criteria of response were weight gain, plasma inorganic phosphorus and feed consumption. The heifers fed the basal ration made significantly slower gains and had lower plasma inorganic phosphorus as compared to heifers fed the

supplemented rations. All of the phosphorus supplements tested appeared to be about equal in value for promoting gain in weight, plasma inorganic phosphorus, and feed consumption of beef heifers.

EXPERIMENT IV

A COMPARISON OF DICALCIUM PHOSPHATE, STEAMED BONE MEAL, AND CURA-PHOS AS SOURCES OF PHOSPHORUS FOR WETHER LAMBS

A considerable saving in experimental cost could be effected if it were possible to apply phosphorus availability data obtained with lambs to the feeding of cattle. This experiment was designed to furnish data relating to the above factors, as well as to determine the availability to lambs of phosphorus from the various phosphorus supplements.

Experimental Procedure

Twenty-four western wether lambs weighing approximately 70 lb. were used in this experiment. The lambs were drenched, sheared, and then placed on the basal ration (ration 1), composition shown in table 16, for a 48-day depletion period (period 1). On December 23, 1955, the lambs were randomly allotted to one of the four treatments. One-half percent salt was added to the rations. All other details were as in experiment III.

Results

Weight Gain

The results obtained during period 2 are shown in table 20.

The lambs receiving the basal ration gained significantly less (P of less than .01) than those receiving supplemental phosphorus supplied

Table 20. Average Weight Gain of Lambs
Period 2
(pounds)

Period ending	Ration 1	Ration 2	Ration 3	Ration 4
December 31, 1955*	2	3	2	3
January 14	1	4	7	3
January 28	2	6	5	7
February 11	1	4	7	4
February 25	2	5	3	6
March 10	-1	4	4	2
March 17	1	2	3	5
Av. total gain	8	28	31	30

*Average initial weights on December 17 were 87, 78, 69, and 79 lb. for the lambs fed rations 1, 2, 3, and 4, respectively.

by steamed bone meal, Cura-Phos,* or dicalcium phosphate. During the 85-day feeding period, the lambs fed rations 1, 2, 3, and 4 gained 0.09, 0.33, 0.36, and 0.35 lb. daily, respectively.

Plasma Inorganic Phosphorus

The plasma phosphorus data obtained during period 2 are shown in table 21.

At the end of period 1, the lambs allotted to rations 1, 2, 3, and 4 had average plasma inorganic phosphorus values of 3.3, 3.5, 3.3, and 3.3 mg. percent, respectively. At the end of period 2, the basal-fed group had an average value of 2.3 mg. percent; those fed ration 2 (steamed bone meal), ration 3 (Cura-Phos), and ration 4 (dicalcium phosphate) had values of 5.1, 5.5, and 5.6 mg. percent, respectively. The lambs fed the basal ration gained significantly less (P of less than .01) in plasma inorganic phosphorus as compared to the gain of the lambs

*Cura-Phos is the trade name for Curacao Island Phosphate.

Table 21. Plasma Inorganic Phosphorus
Period 2
(mg. P/100 ml. plasma)

Date	Ration 1	Ration 2	Ration 3	Ration 4
December 17, 1955	3.31	3.51	3.31	3.26
December 31	3.67	5.37	5.32	5.84
January 14	1.75	3.24	3.28	3.41
January 28	2.82	5.33	5.23	5.90
February 4	2.64	4.55	5.15	5.39
February 11	2.57	4.04	5.79	5.49
February 25	2.64	4.40	5.70	5.95
March 10	2.53	5.20	5.74	5.91
March 17	2.29	5.14	5.51	5.58
Av. total gain	-1.02	1.63	2.20	2.32

fed the phosphorus supplemented rations. There were no significant differences in the gain in plasma inorganic phosphorus of the lambs fed rations 2, 3, and 4.

<u>Daily Feed Consumption</u>

The results obtained during period 2 are shown in table 22.

The average daily feed consumption during period 2 was 2.57, 3.24, 3.07, and 3.18 lb. for rations 1, 2, 3, and 4, respectively. The feed consumption of the lambs fed the basal ration showed a consistent decline during period 2, this amounted to 0.71 lb. daily, when final feed consumption was compared to initial. During this same period the lambs fed rations 2, 3, and 4 increased 0.42, 1.17, and 0.73 lb. in daily feed consumption, respectively. The feed required per 100 lb. of gain was 2855, 951, 853, and 909 lb. for the lambs fed rations 1 (basal), 2 (bone-meal), 3 (Cura-Phos), and 4 (dicalcium phosphate), respectively. This is in agreement with the results observed by Beeson <u>et al</u>. (1944) who

Table 22. Average Daily Feed Consumption
Period 2
(pounds)

Period ending	Ration 1	Ration 2	Ration 3	Ration 4
December 31, 1955	2.85	3.04	2.27	2.62
January 14	2.93	2.91	2.87	3.08
January 28	2.65	3.03	3.11	3.18
February 11	2.49	3.11	3.06	3.11
February 25	2.54	3.51	2.93	3.30
March 10	2.33	3.62	3.55	3.43
March 17	2.14	3.46	3.44	3.33

reported that utilization of feed was affected more acutely than the appetite of lambs fed low-phosphorus rations.

Discussion

If the growth response of lambs to added dicalcium phosphate were arbitrarily assigned the value of 100, the values of steamed bone meal and Cura-Phos, respectively, were 90 and 105. If plasma inorganic phosphorus were used as the criteria the values were 80 and 96, respectively. Differences in plasma inorganic phosphorus levels were significant (P of less than .01) within 8 days after the animals were placed on the different treatments, whereas the differences in gain were not significant at the same probability level until approximately 42 days later. In this experiment plasma inorganic phosphorus was the most sensitive measure of the level of phosphorus nutrition. The results determined by this method were confirmed by changes in body weight approximately one month later.

The level of plasma inorganic phosphorus was observed to fluctuate from bleeding to bleeding. To determine if this could be due to hemolysis the lambs were bled on February 4, the plasma was analyzed for phosphorus content on the same day and again 5 days later. A positive correlation of 0.99 was observed between the two analyses. This ruled out the possibility of hemolysis being the cause of variation.

The weight gains and feed efficiencies were almost identical for the lambs fed supplemented rations. However, lambs fed the basal ration gained approximately 20 percent as much as those fed the supplemented rations, while consuming 80 percent as much feed.

There were no observed differences in the general appearance of the lambs fed the four rations. However, in the latter part of period 2, wool eating was observed in the lambs fed the basal ration. No other sign of abnormal appetite was observed, and no bone abnormalities were observed. From the results obtained in this experiment, the availability of phosphorus from steamed bone meal, Cura-Phos, and dicalcium phosphate appears to be relatively equal.

Fluoride toxicity does not appear to be a problem in the addition of Cura-Phos to lamb rations. In this experiment Cura-Phos furnished 0.08 percent phosphorus in the ration, the fluorine content of the ration was 275 ppm., and no deleterious effects were observed. Mitchell and Edman (1952) reported that about 100 ppm. of fluorine supplied in rock phosphate was on the borderline of toxicity in sheep. Hobbs et al. (1954) reported that wether lambs fed rations with 200 ppm. of fluorine added as sodium fluoride showed a slight decrease in feed consumption and no decrease in phosphorus level of blood serus after five months on the ration.

Summary

Four groups of 6 wether lambs each were used to determine the relative values of steamed bone meal, Cura-Phos, and dicalcium phosphate as inorganic phosphorus supplements for lambs. One group was fed a low-phosphorus basal ration, 0.07 percent phosphorus, the other three groups were fed the basal ration supplemented with 0.08 percent phosphorus as steamed bone meal, Cura-Phos, or dicalcium phosphate. Criteria of response were weight gain, plasma inorganic phosphorus, and feed consumption. The lambs fed the basal ration made significantly slower gains and had lower plasma inorganic phosphorus as compared to the lambs fed the supplemented rations. All of the phosphorus supplements tested appeared to be about equal in value for promoting gain in weight and plasma inorganic phosphorus.

SUMMARY

Two studies, involving 9 grade Hereford steers each, were conducted to determine the relative values of weight gain, plasma inorganic phosphorus, and feed consumption as measures of the level of phosphorus nutrition of steers fed rations containing graduated levels of phosphorus, and to determine the most desirable level of phosphorus intake at which to study the availability of phosphorus in various phosphorus supplements fed to ruminants. Twenty-four beef heifers were used to determine the relative availability of phosphorus in soft phosphate with colloidal clay and dicalcium phosphate. Thirty-one beef heifers and 24 wether lambs were used to determine the relative availability of phosphorus in steamed bone meal, Cura-Phos, and dicalcium phosphate. Criteria of response were plasma inorganic phosphorus, weight gain, and feed consumption.

Changes in the level of phosphorus nutrition of steers were detected by changes in plasma inorganic phosphorus within one week, and by changes in feed consumption or body weight in from 30 to 60 additional days. When levels of phosphorus ranged from 0.07 to 0.15 percent, there was a significant linear effect on all criteria used.

The feeding of colloidal clay to beef heifers resulted in significantly lower gains and ash content of cannon bones or mandibles than the feeding of dicalcium phosphate. If the growth of beef heifers fed dicalcium phosphate were assigned a value of 100, the values for colloidal clay, steamed bone meal, and Cura-Phos were 17, 99, and 115,

respectively. If plasma inorganic phosphorus were used as the criteria the values in the same order were 45, 198, and 144. The phosphorus in all supplements tested, with the exception of colloidal clay, appeared to be about equal in availability to beef heifers. If the growth response of lambs to added dicalcium phosphate were assigned the value of 100, the values of steamed bone meal and Cura-Phos, were 90 and 105. If plasma inorganic phosphorus were used as the criteria the values were 80 and 96, respectively. All of the phosphorus supplements tested appear to be about equal in value, when fed to lambs, for promoting gain in weight and plasma inorganic phosphorus.

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APPENDIX

Table 23. Body Weight of Steers
Part 1 in Experiment I
(pounds)

Steer No.	Period Ending												
	12/27	12/28	1/15	1/29	2/17	3/3	3/17	3/31	4/14	4/28	5/12	5/26	6/15
						Ration 1							
2	400	400	425	380	403	420	433	429	443	447	437	437	430
4	395	400	420	375	395	405	420	415	430	440	435	437	432
8	390	405	425	395	417	415	435	447	432	450	443	455	440
Av.	395	402	423	383	405	413	429	430	435	446	438	443	434
						Ration 2							
9	410	420	435	390	410	424	450	463	483	498	512	548	547
1	365	375	425	375	394	410	421	440	455	480	490	520	530
6	395	400	410	380	408	399	430	444	465	485	505	545	540
Av.	390	398	423	382	404	411	434	449	468	488	502	538	539
						Ration 3							
7	400	400	420	380	412	431	455	465	488	501	530	555	562
3	395	400	435	385	420	431	458	470	498	512	540	577	575
5	365	380	410	360	385	370	421	433	430	472	490	491	515
Av.	387	393	422	375	406	411	445	456	472	495	520	541	551

Table 24. Plasma Inorganic Phosphorus of Steers
Part 1 in Experiment I
(mg. P/100 ml. plasma)

Steer No.	Period Ending											
	1/21	2/5	2/17	3/3	3/18	3/31	4/5	4/14	4/28	5/12	5/26	6/15
						Ration 1						
2	3.72	4.88	4.84	4.88	3.96	3.60	3.72	3.32	3.40	2.92	3.36	2.88
4	2.68	3.28	2.92	3.28	2.92	3.36	3.00	2.84	2.90	2.64	3.00	3.08
8	2.64	4.28	3.00	3.36	4.32	7.68	5.76	4.60	5.44	5.32	7.32	4.12
Av.	3.01	4.15	3.58	3.84	3.73	4.88	4.16	3.59	3.91	3.63	4.56	3.36
						Ration 2						
9	2.64	4.28	3.00	3.36	4.32	7.68	5.76	4.60	5.44	5.32	7.32	4.12
1	6.12	4.88	5.32	4.88	3.72	5.12	4.88	5.80	7.28	6.44	5.64	6.60
6	3.28	3.16	2.96	3.20	3.72	6.20	4.48	4.28	5.60	4.88	5.48	5.56
Av.	4.01	4.11	3.76	3.81	3.92	6.33	5.04	4.89	6.11	5.55	6.15	5.43
						Ration 3						
7	3.28	3.84	3.68	3.64	6.32	5.40	5.84	7.84	8.76	5.92	6.64	6.20
3	3.35	4.08	4.16	3.68	4.60	4.48	5.16	8.68	8.88	6.64	8.00	5.80
5	3.36	3.88	3.12	3.60	4.96	5.12	4.88	6.92	8.42	7.12	7.84	6.28
Av.	3.33	3.93	3.65	3.64	5.29	5.00	5.29	7.81	8.69	6.56	7.49	6.09

Table 25. Daily Feed Consumption of Steers
Part 1 in Experiment I
(pounds)

Steer No.	Period Ending 2/14	3/3	3/17	3/31	4/14	4/28	5/12	5/28	6/15
					Ration 1				
2	6.99	7.71	8.74	7.41	9.14	5.79	5.07	5.21	4.84
4	6.99	6.34	8.74	6.44	8.36	6.14	5.07	5.21	4.61
8	6.99	7.56	8.74	8.07	9.21	6.86	4.68	5.50	4.72
Av.	6.99	7.20	8.74	7.30	8.90	6.26	4.94	5.31	4.72
					Ration 2				
9	6.99	7.76	8.63	8.00	9.93	9.43	10.00	10.21	10.00
1	6.99	7.95	8.74	7.78	9.93	9.43	10.00	9.75	10.00
6	6.99	6.59	8.74	8.37	9.93	9.43	10.00	10.10	10.00
Av.	6.99	7.43	8.70	8.05	9.93	9.43	10.00	10.02	10.00
					Ration 3				
7	6.99	7.95	8.74	8.37	9.93	9.43	10.00	10.00	10.00
3	6.99	7.80	8.74	8.07	9.93	9.43	10.00	10.07	10.00
5	6.99	6.44	8.74	8.07	9.93	9.43	10.00	10.07	10.00
Av.	6.99	7.40	8.74	8.17	9.93	9.43	10.00	10.04	10.00

Table 26. Body Weight of Steers
Part 2 in Experiment I
(pounds)

Steer No.	Period Ending 11/20	12/10	12/23	1/7	1/21	2/4	2/18	3/3	3/17	3/31
					Ration 1					
1	360	390	390	405	420	430	448	445	440	440
4	320	360	345	350	350	350	365	365	365	375
5	320	335	325	335	335	332	330	335	345	335
Av.	333	362	353	363	368	371	381	382	383	383
					Ration 2					
9	360	400	390	405	420	418	453	465	495	485
2	330	350	350	363	360	365	390	390	410	410
3	320	330	335	355	360	370	385	400	410	420
Av.	337	360	358	374	380	384	409	418	438	438
					Ration 3					
6	375	400	385	395	410	435	453	475	495	500
7	370	365	370	385	490	395	410	425	445	450
8	340	350	342	345	360	370	405	420	435	450
Av.	362	372	365	375	387	402	423	440	458	467

Table 27. Plasma Inorganic Phosphorus of Steers
Part 2 in Experiment I
(mg. P/100 ml. plasma)

Steer No.	Period Ending 11/20	12/10	12/23	1/7	1/21	2/4	2/18	3/3	3/17	3/31
					Ration 1					
1	5.68	3.68	4.60	4.04	3.72	3.92	3.08	3.20	2.84	2.92
4	5.80	2.80	3.80	3.48	3.38	3.04	2.76	2.76	2.64	2.56
5	6.96	4.60	4.24	4.32	3.38	3.60	3.84	2.72	3.20	2.92
Av.	6.15	3.69	4.21	3.91	3.49	3.52	3.23	2.89	2.89	2.80
					Ration 2					
9	7.92	3.72	4.32	5.36	5.80	6.28	4.40	4.60	4.00	3.92
2	6.48	3.60	4.76	5.80	6.04	6.92	6.00	5.48	5.24	5.32
3	5.68	2.92	3.84	5.44	5.64	5.64	3.80	4.64	4.08	3.28
Av.	6.69	3.41	4.31	5.53	5.82	6.28	4.73	4.91	4.44	4.17
					Ration 3					
6	7.92	3.32	4.28	5.72	6.68	6.00	6.08	6.16	6.48	6.48
7	8.20	4.68	5.04	5.60	8.00	6.56	6.64	7.36	6.60	5.76
8	5.64	4.40	5.80	5.64	6.60	6.08	4.88	5.56	6.48	5.40
Av.	7.25	4.13	5.04	5.65	7.09	6.21	5.87	6.36	6.52	5.80

Table 28. Daily Feed Consumption of Steers
Part 2 in Experiment I
(pounds)

Steer No.	Period Ending 12/3	12/23	1/2	1/6	1/21	2/4	2/18	3/3	3/17	3/31
					Ration 1					
1	9.28	7.67	7.90	8.00	7.77	8.04	8.64	7.70	6.80	6.93
4	9.28	6.50	5.40	6.20	4.00	4.32	5.54	5.60	6.10	5.93
5	9.28	5.55	4.70	5.90	4.04	4.14	3.54	3.60	3.50	3.21
Av.	9.28	6.56	6.00	6.70	5.27	5.50	5.91	5.60	5.50	5.36
					Ration 2					
2	9.28	6.08	5.30	5.60	4.96	5.86	6.57	6.90	7.80	8.04
3	9.28	6.59	6.25	6.70	6.54	6.79	7.04	7.90	8.60	9.00
9	9.28	7.09	8.45	7.90	7.87	8.14	8.89	9.90	11.20	12.00
Av.	9.28	6.59	6.67	6.70	6.46	6.93	7.50	8.20	9.20	9.68
					Ration 3					
6	9.28	5.88	6.70	7.20	7.59	8.39	9.07	9.75	10.40	11.75
7	9.28	6.21	8.25	8.50	8.12	7.79	8.21	8.95	9.86	14.00
8	9.28	6.28	5.90	6.10	6.85	8.36	9.53	10.20	10.60	11.18
Av.	9.28	6.12	6.95	7.30	7.52	8.18	8.94	9.60	10.32	12.31

Table 29. Body Weight of Heifers
Experiment II
(pounds)

Heifer No.	Period 1					Period 2								Period 3				
	12/27	12/28	1/15	1/29	3/3	3/5	3/20	4/2	4/17	4/30	5/14	5/28	6/11	7/3	7/15	7/29	8/16	8/30
						Ration 1								Ration 3				
4	415	430	470	470	500	475	485	490	495	500	500	510	500					
6	400	405	420	440	460	450	470	475	470	475	475	480	475					
10	475	480	515	515	535	510	545	520	545	545	565	565	560					
12	470	495	520	535	550	520	525	545	550	545	545	550	560					
51	395	400	425	440	500	475	490	500	520	525	520	520	525	510	495	510	520	520
52	375	385	410	410	435	410	425	415	435	430	430	440	430	455	455	485	500	500
55	370	380	400	410	455	425	435	445	480	475	520	495	485	515	510	550	565	585
56	365	390	435	430	475	450	465	465	490	490	480	485	490	520	540	565	585	605
Av.	408	421	449	456	489	464	480	482	498	498	504	506	503	500	500	528	543	553
									Ration 2									
3	385	400	445	445	475	450	465	475	495	485	500	505	515					
5	355	375	380	405	435	410	430	450	470	465	470	495	460					
8	510	530	575	580	635	605	615	640	665	660	680	670	680					
11	400	400	430	470	525	500	515	540	555	570	575	585	570					
47	390	395	430	450	495	470	495	530	540	555	565	585	570	585	580	605	630	630
50	390	395	420	425	485	460	485	480	510	500	485	505	505	510	495	515	510	535
53	385	405	420	415	425	415	450	455	460	460	470	455	440	430	450	430	450	440
57	410	415	405	430	460	435	470	470	475	475	465	465	450	440	430	420	425	430
Av.	403	414	438	453	492	468	491	505	521	521	526	533	523	491	489	493	504	509

Table 29 (Continued)

Heifer No.	Period 1					Period 2								Period 3				
	12/27	12/28	1/15	1/29	3/3	3/5	3/20	4/2	4/17	4/30	5/14	5/28	6/11	7.3	7/15	7/29	8/16	8/30
									Ration 3									
1	470	480	520	540	530	515	560	580	600	595	605	610	600					
2	370	380	410	425	465	445	490	510	540	560	585	620	640					
7	435	450	500	515	575	530	590	615	665	680	700	690	725					
9	425	440	445	460	490	465	505	520	550	560	585	600	600					
46	400	405	435	445	470	465	510	525	560	585	605	620	620	635	655	670	700	690
48	465	390	410	375	400	390	420	430	480	470	460	495	490	525	530	570	590	610
49	435	450	465	475	495	465	515	520	540	550	580	575	580	580	580	595	605	605
54	365	375	425	440	500	475	520	550	585	600	620	650	655	640	645	690	725	745
Av.	421	421	451	459	491	468	514	531	565	575	593	608	614	595	603	631	655	663

Table 30. Plasma Inorganic Phosphorus of Heifers
Experiment II
(mg. P/100 ml. plasma)

Heifer No.	Period 2				Period 3					
	3/5	4/17	5/19	6/11	6/21	7/3	7/15	7/29	8/16	8/30
	Ration 1				Ration 3					
4	2.40	3.96	2.56	2.44						
6	2.52	2.28	1.88	1.72						
10	3.68	3.08	2.84	2.12						
12	3.04	3.36	2.36	2.24						
51	2.60	2.24	2.00	1.52	2.64	2.24	2.64	2.64	3.36	2.64
52	2.64	2.64	2.16	2.12	2.08	2.56	2.36	3.20	3.28	2.04
55	2.68	2.84	2.28	2.20	2.92	2.80	2.84	3.80	2.52	2.68
56	3.20	3.40	2.36	1.96	2.80	3.80	3.68	3.80	2.64	3.48
Av.	2.85	2.98	2.31	2.04	2.61	2.85	2.88	3.36	2.95	2.71
	Ration 2				Ration 2					
3	2.76	4.28	3.48	3.68						
5	2.72	3.28	3.24	2.52						
8	2.48	3.60	3.28	3.08						
11	3.20	3.96	3.72	3.36						
47	2.60	3.44	3.04	2.56	3.28	3.20	3.04	3.32	2.56	2.30
50	3.28	4.36	3.32	2.92	3.28	3.28	2.92	2.40	3.60	2.30
53	2.48	2.68	3.04	2.56	2.24	2.68	2.52	2.28	2.08	3.16
57	1.76	2.60	2.24	1.56	2.28	2.40	2.64	2.36	2.28	1.76
Av.	2.66	3.53	3.77	2.78	2.77	2.89	2.78	2.59	2.63	2.38

Table 30 (Continued)

Heifer No.	Period 2				Period 3					
	3/5	4/17	5/19	6/11	6/21	7/3	7/15	7/29	8/16	8/30
	Ration 3				Ration 3					
1	2.64	3.16	2.84	2.40						
2	3.44	4.16	4.60	3.80						
7	3.64	6.28	5.32	4.48						
9	3.40	4.40	4.60	4.36						
46	2.84	4.80	4.44	3.68			4.56	3.68	3.28	2.80
48	2.52	4.40	2.28	2.32			3.40	3.96	3.36	3.24
49	2.24	3.20	3.28	2.80			2.24	3.16	2.76	2.48
54	3.76	6.40	6.04	5.52			5.20	5.20	4.80	5.20
Av.	3.06	4.60	4.18	3.67			3.85	4.00	3.55	3.43

Table 31. Bone-ash of Crossbred Heifers
Period 2 in Experiment II
(percent)

Heifer No.	Cannon Bone	Mandible Bone
	Ration 1	
4	59.56	62.10
6	55.39	61.79
10	56.00	63.84
12	57.40	62.17
Av.	57.09	62.48
	Ration 2	
3	57.96	61.26
5	53.54	60.51
8	52.52	61.47
11	55.62	62.36
Av.	54.91	61.40
	Ration 3	
1	58.87	60.43
2	62.54	65.13
7	58.72	64.86
9	58.72	66.92
Av.	59.71	64.34

Table 32. Body Weight of Heifers
Experiment III
(pounds)

Heifer No.	Period Ending									
	11/20	12/10	12/23	1/7	1/21	2/4	2/18	3/3	3/17	3/31
					Ration 1					
38	400	420	445	450	465	485	500	510	530	530
43	410	445	465	475	495	470	495	515	520	510
44	410	435	460	480	480	500	500	490	475	470
46	425	440	470	475	485	475	490	500	490	470
53	440	460	485	490	495	470	480	460	465	440
54	415	420	455	450	465	470	470	460	460	440
55	510	540	580	580	590	590	570	595	580	545
59	415	410	460	465	480	505	510	520	545	520
Av.	428	446	478	483	494	496	502	506	508	491
					Ration 2					
32	400	435	475	470	505	580	565	580	600	610
34	390	410	440	450	490	510	530	535	560	575
37	420	445	475	470	500	500	540	550	560	565
50	390	390	430	415	450	470	500	510	530	530
52	415	440	450	465	480	520	535	550	580	580
56	410	430	480	465	480	500	510	540	535	545
62	460	490	520	530	560	585	610	645	670	680
Av.	412	434	467	466	495	524	541	559	576	584

Table 32 (Continued)

Heifer No.	Period Ending 11/20	12/10	12/23	1/7	1/21	2/4	2/18	3/3	3/17	3/31
					Ration 3					
31	390	410	445	435	470	490	500	515	520	530
33	395	410	440	450	465	500	520	535	565	580
40	435	470	500	500	540	580	610	630	655	705
45	350	360	400	390	440	450	480	505	540	570
49	345	365	395	375	415	445	465	470	505	500
51	410	440	450	460	495	490	500	545	550	565
57	440	470	500	500	530	560	525	600	635	640
61	410	410	420	430	460	480	475	510	520	540
Av.	397	417	444	443	477	499	509	539	561	579
					Ration 4					
35	370	390	405	420	435	460	485	500	490	495
36	350	375	410	385	415	440	470	500	520	530
39	380	395	430	440	490	520	550	590	615	625
41	410	415	450	460	480	505	540	570	580	600
42	460	450	480	495	505	520	550	565	590	590
47	400	405	445	440	475	490	510	540	560	550
48	375	385	420	415	440	460	470	500	510	515
60	440	460	505	525	525	545	560	595	590	580
Av.	398	409	443	447	471	492	517	545	557	561

Table 33. Plasma Inorganic Phosphorus of Heifers
Experiment III
(mg. P/100 ml. plasma)

Heifer No.	Period Ending 11/20	12/3	12/23	1/7	1/21	2/4	2/18	3/3	3/17	3/31
					Ration 1					
38	7.88	3.48	3.96	3.72	3.36	3.16	2.96	3.28	2.48	2.72
43	6.08	3.28	3.00	4.24	3.08	3.24	2.76	2.64	2.68	2.16
44	6.92	4.00	4.20	4.24	3.24	3.04	2.56	2.72	3.44	2.48
46	7.08	4.24	3.92	3.28	3.40	3.60	2.20	2.76	2.92	2.68
53	6.12	3.08	2.68	3.72	2.45	2.56	2.12	2.72	1.88	2.36
54	6.32	2.36	2.70	2.68	2.04	2.40	1.82	2.64	2.60	1.88
55	5.64	2.52	1.44	2.00	2.00	2.28	1.72	2.16	2.40	2.28
59	8.04	4.48	4.44	4.08	3.36	3.08	2.52	2.56	2.72	2.36
Av.	6.78	3.43	3.29	3.49	2.87	2.92	2.33	2.69	2.64	2.36
					Ration 2					
32	7.12	3.68	3.68	3.68	4.24	4.08	4.36	4.08	4.12	3.72
34	7.08	3.52	3.84	5.12	4.76	4.20	5.16	4.96	4.36	4.08
37	6.36	5.08	2.88	5.32	5.16	6.24	5.52	6.04	5.52	5.16
50	7.88	3.36	2.12	5.32	4.60	5.16	4.60	5.42	4.16	3.48
52	7.92	3.04	3.08	4.96	6.00	5.64	5.56	6.12	5.80	6.12
56	6.92	2.16	1.52	2.84	2.84	3.00	3.60	3.16	3.68	3.20
62	5.80	2.84	2.56	4.92	4.56	5.40	5.00	5.28	5.52	5.48
Av.	7.01	3.38	2.81	4.59	4.02	4.82	4.83	5.01	4.74	4.46

Table 33 (Continued)

Heifer No.	Period Ending									
	11/20	12/3	12/23	1/7	1/21	2/4	2/18	3/3	3/17	3/31
					Ration 3					
31	6.60	4.00	3.92	4.68	3.84	4.72	3.68	3.84	4.24	3.76
33	5.48	2.72	3.08	4.08	4.80	4.76	3.60	4.28	3.96	4.60
40	6.00	3.76	2.80	4.64	6.68	6.12	4.84	4.48	5.96	5.88
45	5.24	4.24	3.32	5.12	6.80	7.40	5.32	4.24	5.88	4.44
49	5.28	3.08	3.80	6.20	6.28	6.44	4.64	4.72	3.96	4.12
51	7.48	2.92	3.28	5.04	4.16	4.36	4.12	3.80	4.88	3.76
57	7.12	4.36	3.48	4.72	4.36	4.20	3.80	4.76	4.40	3.68
61	6.16	2.64	3.08	4.16	4.68	4.00	3.48	3.76	3.96	4.00
Av.	6.17	3.47	3.35	4.83	5.20	5.25	4.18	4.24	4.66	4.28
					Ration 4					
35	6.84	3.72	4.00	4.88	4.36	5.92	6.20	4.24	3.80	3.48
36	6.08	3.00	3.20	6.92	6.00	4.56	5.20	4.60	4.60	4.48
39	7.88	2.92	4.08	4.08	5.44	5.92	5.76	5.08	5.32	5.20
41	7.16	3.64	3.80	6.64	6.52	5.20	5.12	4.36	5.28	4.76
42	6.12	3.16	2.72	4.08	3.32	3.52	4.04	4.84	3.88	3.36
47	8.16	3.04	3.84	5.08	4.96	4.60	4.92	5.28	4.20	3.08
48	6.84	4.80	3.56	3.96	4.08	4.20	4.52	4.20	4.24	3.84
60	6.32	2.92	2.92	3.92	4.24	3.32	4.40	4.00	3.28	2.28
Av.	6.93	3.40	3.52	4.94	4.74	4.65	5.02	4.58	4.33	3.88

Table 34. Body Weight of Lambs
Experiment IV
(pounds)

Lamb No.	Period Ending									
	11/5	12/3	12/17	12/31	1/14	1/28	2/11	2/25	3/10	3/17
					Ration 1					
5	71	79	80	81	80	80	82	81	82	84
6	83	87	90	92	91	93	92	92	89	90
17	74	81	86	86	87	87	89	90	89	90
20	82	87	94	99	104	110	114	116	118	118
28	76	86	91	93	96	99	102	104	104	106
33	76	80	82	83	80	81	82	84	84	83
Av.	77	83	87	89	90	92	93	95	94	95
					Ration 2					
11	58	61	62	63	63	66	69	68	69	70
15	85	80	84	82	88	94	103	107	115	117
16	67	66	67	70	73	77	82	85	91	93
27	83	92	95	98	103	112	117	126	130	132
36	67	75	77	84	92	101	103	108	110	111
37	73	79	85	90	93	95	95	102	105	108
Av.	69	76	78	81	85	91	95	99	103	105

Table 34 (Continued)

Lamb No.	Period Ending 11/5	12/3	12/17	12/31	1/14	1/28	2/11	2/25	3/10	3/17
					Ration 3					
3	56	60	63	66	71	76	81	83	87	88
7	64	67	70	71	78	82	90	94	96	99
22	74	72	69	69	74	87	96	90	94	98
24	73	82	84	88	96	102	107	113	116	119
29	60	70	72	75	80	81	91	98	99	102
47	58	58	56	59	66	71	77	84	90	93
Av.	64	68	69	71	78	83	90	93	97	100
					Ration 4					
1	74	78	81	84	90	94	97	103	106	112
8	65	70	74	79	84	91	95	101	99	104
13	68	69	74	76	80	85	92	101	106	113
14	76	78	82	83	88	91	94	99	100	104
32	73	79	81	85	88	91	98	102	104	109
44	76	83	81	86	92	97	101	106	109	111
Av.	72	76	79	82	85	92	96	102	104	109

Table 35. Plasma Inorganic Phosphorus of Lambs
Experiment IV
(mg. P/100 ml. plasma)

Lamb No.	Period Ending											
	11/5	12/3	12/17	12/31	1/14	1/28	2/4	2/4	2/11	2/25	3/10	3/17
						Ration 1						
5	5.80	4.48	3.48	4.48	1.84	2.56	2.64	2.78	3.04	3.12	2.36	2.28
6	5.00	3.56	3.60	5.04	2.28	4.40	3.40	3.36	3.40	3.48	4.08	2.48
17	6.08	3.20	3.32	3.28	1.64	2.28	2.28	2.24	2.24	2.64	2.56	2.32
20	4.04	3.36	3.60	3.64	1.64	2.92	2.68	2.60	2.44	2.84	2.08	2.24
28	4.24	3.56	3.44	2.92	1.36	2.48	2.72	2.40	2.12	2.00	1.84	2.28
33	4.08	2.72	2.40	2.64	1.72	2.28	2.12	2.00	2.20	1.76	2.28	2.12
Av.	4.87	3.48	3.31	3.67	1.75	2.82	2.64	2.56	2.57	2.64	2.53	2.29
						Ration 2						
11	5.20	3.48	3.32	5.76	3.00	5.16	4.40	4.48	5.80	4.16	4.88	4.60
15	4.60	2.56	3.32	4.24	3.80	5.20	4.72	4.92	5.00	6.36	5.84	6.08
16	7.84	3.08	2.72	5.56	3.36	5.76	4.60	4.64	4.60	4.76	5.44	5.28
27	5.12	3.28	3.56	5.08	3.28	5.80	4.68	4.80	6.48	5.24	4.60	5.40
36	4.08	3.20	4.36	6.72	3.28	5.72	4.36	4.72	5.92	5.92	5.44	5.28
37	2.80	3.28	3.80	4.84	2.72	4.32	4.48	4.36	4.04	4.40	5.20	4.20
Av.	4.94	3.15	3.51	5.37	3.24	5.33	4.55	4.65	5.31	5.14	5.23	5.14

Table 35 (Continued)

Lamb No.	Period Ending 11/5	12/3	12/17	12/31	1/14	1/28	2/4	2/4	2/11	2/25	3/10	3/17
						Ration 3						
3	3.48	3.36	3.52	4.96	2.12	4.04	4.52	4.40	5.64	4.60	4.88	3.40
7	5.04	3.48	2.68	4.92	2.68	4.44	6.00	5.92	4.92	4.96	4.88	4.88
22	5.04	3.96	2.84	3.92	2.24	5.24	4.40	4.28	5.76	4.32	5.80	5.00
24	3.28	3.60	3.68	6.68	5.20	6.56	6.12	5.96	6.92	8.76	7.20	7.36
29	5.20	4.60	4.04	5.92	4.24	5.04	4.80	4.68	6.08	5.84	5.52	6.48
47	8.40	2.72	3.08	5.52	3.20	6.08	5.04	5.00	5.40	5.72	6.16	5.96
Av.	5.07	3.62	3.31	5.32	3.28	5.23	5.15	5.04	5.79	5.70	5.74	5.51
						Ration 4						
1	5.88	3.16	3.60	6.96	4.04	6.16	4.88	4.80	5.28	6.56	6.12	5.24
8	4.96	3.28	2.76	6.32	2.76	5.88	4.44	4.16	5.84	5.20	5.04	5.52
13	3.84	3.36	3.08	4.78	2.96	5.12	5.92	5.80	5.40	6.60	6.60	5.76
14	2.88	3.08	3.64	5.04	3.28	5.08	5.72	5.84	5.40	5.20	5.80	5.28
32	7.20	3.00	3.00	7.32	3.48	6.00	5.80	5.60	5.40	6.20	6.24	5.96
44	3.00	4.40	3.48	4.64	3.96	7.16	5.56	5.44	5.64	5.96	5.68	5.72
Av.	4.63	3.38	3.26	5.84	3.41	5.90	5.39	5.27	5.49	5.95	5.91	5.58

VITA

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