PHOSPHORUS STUDIES OF RANGE BEEF CATTLE

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by

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INTRODUCTION

The problem of the mineral requirements of range livestock and of the optimum mineral composition of range herbage necessary for profitable range livestock production is a field of nutrition which warrants additional study. During the last ten years, many so called "sick areas" have been found to be deficient in one or more mineral elements and corrective measures discovered for reclaiming these areas for livestock production. The problem in many other "sick areas" needs to be investigated.

The occurrence of abnormal conditions of cattle due to a deficiency of available phosphorus in pasturage, hay and other feeds has been reported from many localities in the United States and other countries. Under prevailing conditions of farm and range, probably no dietary deficiency of livestock, particularly cattle, is more prevalent than a deficiency of phosphorus. The problem of phosphorus deficiencies in animal nutrition has been brought about by the removal of this element from the soil by cropping, weathering and leaching as well as the increased requirements co-existent with increased production through improved methods of breeding and management. This deficiency is commonly associated with soils that are deficient in this element, but some investigations clearly indicate that this condition might be encountered anywhere regardless of the phosphorus content of the soil as a result of ill-chosen rations.

Livestock men for many years have quickly recognized the losses from disease and poisonous plants because they are relatively quick in their action and produce marked symptoms which are readily recognized as deviations from the normal with greater or less mortality in a few days or weeks. Nutritional deficiencies, such as a lack of available phosphorus are, on the other hand, slow and insidious in their development resulting in suboptimal performance. Entire herds may be affected and become unthrifty without actual mortality or any tangible evidence being recognized as to the source of the disturbance either by clinical observation or post-mortem examination.

Recognition of the importance of phosphorus in a livestock feeding program has resulted in extensive and widespread research in the field of nutritional diseases which have been responsible, directly or indirectly, for large economic losses in the cattle industry. There is ample evidence, both from experimental studies and from practical observations of stockmen, that phosphorus is responsible in no small measure for the small calf crops, poor gains on apparently good pasturage, calves being born prematurely in the absence of contagious abortion, and other reproductive difficulties.

The accumulation of information with which to study this problem has been greatly increased within recent years, but for the most part present knowledge fails to furnish satisfactory answers to some significant problems relating to the nutritional role of phosphorus in farm animals. Present phosphorus recommendations for beef cattle are based largely on experimental results with dairy cattle and direct application of this work may not be practical under range conditions where animals consume variable amounts of grass of constantly changing composition.

In the following review of literature, therefore, the object will be to present the important and established facts relative to metabolism and the recommended requirements of phosphorus essential for the maintenance of health and the prevention of disease in farm animals. The obvious and urgent need for specific allowances of this element under range beef cattle conditions provides the basis of this study.

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REVIEW OF LITERATURE

It has been said that all living things in the last analysis are dependent for their food supply upon the elemental constituents of the soil. There is, therefore, a continual withdrawal from the soil of these elements which are essential for plant and animal nutrition. Investigations have shown that an impoverished or exhausted soil produces a defective food supply which will result in malnutrition as surely as if the amount of feed were inadequate. Obviously, the well being of our farm animals, aside from infectious diseases, depends mainly upon their state of nutrition. On their well being depends the efficiency of growth, reproduction, lactation, and fattening. The rate at which these functions develop is the main factor, except for market conditions, in the profit derived from the livestock which the soil supports.

Because of its widespread occurrence in the earth's crust, phosphorus has long been recognized as an essential element in the dietary. The requirements of the animal body for phosphorus and its companion element, calcium, for upkeep and normal development has been the subject of widespread research for many years. Conclusive evidence that phosphorus, in combination with calcium, constitutes the greatest portion of the mineral matter of the animal body has been furnished by numerous ash determinations. Maynard (1947) stated that approximately 99 percent of the calcium and 80 percent of the phosphorus of the body were present in the bones and teeth. He further stated that one-half of the remaining phosphorus is present in organic combination as nucleoproteins, phosphoproteins, nucleic acid, adenylic acid, phospholipids, hexosephosphates, triosephosphates, thiamine phosphate, phosphocreatine, and others. The remainder is distributed widely in the body tissues and blood.

The body of a mature cow contains approximately 5 percent ash of which Morgulus (1931) states 36.1 percent is calcium and 16.4 percent phosphorus. It is generally accepted that these two elements constitute about 50 percent of the minerals in the milk where they exist in a ratio of 1.25 to 1. It is clear that the phosphorus secreted in the milk has as its precursors the inorganic phosphates and the phosphatides of the blood.

Studies pertaining to the process of bone formation have shown that two enzymes appear to be involved, namely, phosphorylase and phosphatase. These two enzymes have also been shown to be essential in the conversion of glycogen to glucose. Although calcium and phosphorus exist in the bone in a ratio of 2 to 1, all workers agree that the inorganic composition is roughly but by no means constant, varying considerably among species and with the age of the animal.

In addition to the important role in normal skeletal development, phosphorus is known to be one of the most important elements in the physiological processes of the body. Gortner (1929) stated that phosphorus is concerned in the metabolism of nearly all body tissues. It is present in the nuclei of all cells and is vitally concerned with the complex role in the chain of events occurring in muscular contraction and in the transfer of energy. Phosphorus is considered by nutrition experts to be indispensible in carbohydrate, fat, protein, and lipoid metabolism, and as a constituent of certain enzymes. The maintenance of the reaction of the blood as well as the maintenance of calcium equilibria of the blood are other functions that have been attributed to phosphorus.

Investigations regarding the deposition of the calcium and phosphorus salts in the animal body have clearly demonstrated the nutritive failures following practically complete withdrawal of calcium and phosphorus from rations known to be adequate in other respects. Among the early investigators who studied the effects of rations low in these two essential elements were Chossat (1842), working with pigeons; Weiske (1872), and Weiske and Wildt (1873), who employed sheep and goats; Voit (1880), who used pigeons and later dogs; and Aron and Sebauer (1908) who worked with both rabbits and dogs.

Bone salts are constantly being absorbed and rebuilt. This was conclusively shown by the extensive studies of Hevesy, Levi, and Rebbe (1940) using labelled phosphorus. These investigators found that some of the phosphorus atoms of the mineral constituents of the bone exchange with those present in the blood plasma. Within 50 days, 29 percent of the mineral constituents of the femur and tibia epiphyses were found to be replaced.

The animal body is able to store some of the required minerals when the intake is above that required for maintenance against periods when they are limited or lacking in the food supply. This period of time varies greatly, depending on the particular ingredient, how fast it is utilized, and the reserve supply. Sufficient amounts of calcium and phosphorus must be provided to replace daily losses if the requirements for normal growth, reproduction, lactation and fattening are to occur. Using radioactive phosphorus as an indicator, Harrow (1946) found that within 27 days, 45 percent of the phosphorus given was excreted through the kidney and 11.5 percent through the bowel.

Henderson and Weakley (1930), studying the effects of a low phosphorus ration in dariy cattle, found that a ration containing only 0.133 percent of that mineral materially affected the composition of the bones. The ash content was lowered to less than three-fourths that of normal bones. The calcium and phosphorus content was likewise reduced and the breaking strength of the bones was not much over one-half that of normal bones.

For many years, cattle producers on the veld of South Africa were plagued with small-percentage calf crops, undernourished, slow-maturing cattle, and in many instances with severe death losses, particularly among older animals. Sir Arnold Theiler (1924) associated this disturbance with a lack of available phosphorus which he called aphosphorosis. This condition was rectified by providing any digestible phosphorus compound as a supplement to the natural grazing. The first symptom of a phosphorus deficiency was usually a depraved appetite as evidenced by the chewing of bones, sticks, hair and the excessive ingestion of salt and dirt in an instinctive effort to secure the needed phosphorus. This condition was accompanied by a considerable loss of weight which greatly impaired the development of the body.

In the advanced stages of this deficiency marked skeletal changes occurred which these workers referred to as "styfsiekte". As the depraved appetite, or "pica", become progressively worse, animals frequently ingested carcass debris of animals that had succumbed to the disease. The toxins produced in the decayed carcass by the organism Clostridium botulinum bovis caused lamsiekte, or bovine botulism, which usually proved fatal.

References to bone pathology show that it is one of the major effects of a phosphorus deficiency disease in farm animals. Theiler (1931) reported his examination of the histo-pathology studies of the bones of cattle in South Africa suffering from osteomalacia and rickets. He concluded that the rickets and osteomalacia he observed were very definitely caused by a lack of phosphorus.

Schmidt (1926) observed similar conditions in range cattle on the coastal plains of Texas which have been referred to as loin disease, osteomalacia, and creeps. He observed that as a result of a disturbed mineral metabolism that affected animals became emaciated and weak, frequently suffering fractures of the bones without the application of external force. Many of the calves born alive soon died without showing any symptoms of any specific disease. Growing animals frequently developed a peculiar stiff, creepy gait as though it were painful to walk. Sometimes distinct lameness and stiffness became manifested. Swollen joints and distinct circumscribed enlargements of the distal end of the metatasus and metacarpus were sometimes observed in younger animals.

As calcium and phosphorus are withdrawn from the bones to meet the need for these minerals by the body, the bones become porous and fragile being easily bent. Udall (1939) stated that on sectioning the bones the marrow is red and sprinkled with hemorrhages, while the cortex was thin, spongy and soft. Due to the porosis condition of the bones, aphosphorosis is often called osteoporosis, osteofibrosis in addition to osteomalacia. Madsen (1942) stated that osteomalacia is a disease of adult animals which is characterized by a softening and replacement of bone with osteoid tissue resembling uncalcified bone. Osteoporosis results in marked atrophy without osteod tissue while in osteofibrosis there is partial replacement of the bones with soft, poorly calcified fibrous tissue which may also occupy the marrow cavity.

Areas of phosphorus deficiency in livestock are widespread, particularly in the semi-arid regions of the world and are generally associated with soils that are deficient in this element. Mitchell and McClure (1937) stated that the primary disease as well as the secondary disease developing from it have been reported from every continent on the globe as well as from Central America, New Zealand, Australia, Hawaii, Guam, Cyprus and Tasmania. They further stated that aphosphorosis has been definitely recognized in Montana, Minnesota, Wisconsin, Michigan, Kansas, Utah, California, Texas, Florida and perhaps less certainly in New York, Pennsylvania, West Virginia, Virginia, South Carolina, Alabama, and Mississippi.

All writers on the subject mention the greater prevalence following periods of deficient rainfall. Udall (1939) and Morrison (1940) stated that high producing cows and young growing stock were usually most affected due to their greater needs. Evidence was found in the literature indicating that at least under extreme conditions of mineral shortages, serious disturbances in reproduction occurred. Eckles, Becker, and Palmer (1926) encountered considerable breeding troubles in the phosphorus deficient areas of western Minnesota. On many of those farms, heifers did not show signs of oestrum until two years of age and many of the cows produced a calf every two years. The average calf crop in the most severely affected areas were estimated to be less than 50 percent.

After studying the breeding of cows on phosphorus deficient range for two years, Theiler, Green and DuToit (1928) observed marked breeding deficiencies and found that 80 percent of the cows receiving bone meal supplement on pasture calved normally as against 51 percent in the non-supplemented group. This is in agreement with the results obtained by Hart and Guilbert (1928) in studying the effects of bone meal supplementation on the percent of calf crop in the phosphorus deficient areas of California.

Extensive studies of aphosphorosis in range beef cattle have been conducted on the King Ranch of Texas in cooperation with the United States Department of Agriculture. Black and coworkers (1943) studying the effects of phosphorus supplements on cattle grazing range deficient in this mineral found that the primary advantage in feeding a phosphorus-rich supplement to cows under those conditions was the increased percentage of calf crop and the greater weights attained by the calves at weaning time. Based on a two-year average, this difference was highly significant. Sixty-four percent of the control cows weaned 58 percent of their calves as against 81 percent for the supplemented cows. The authors attribute this difference to the increased milk flow of the cows receiving a phosphorus-rich supplement.

These workers also found that the feeding of phosphorus supplements to cows had no influence on the birth weight of calves. However, on the average for the period covered by the study, the weaning weight per calf in the supplement-fed group was 69 pounds more than the control group. At twelve months of age the difference in average weight between the two groups was essentially the same as at weaning time, but at 18 months of age the former heifers average 126 pounds more than the controls.

Lantow (1933), of the New Mexico Station, found that mineral fed two-year old heifers had much less difficulty at calving than those which received only salt. In 1931, 6 percent of the control heifers required help at calving time and 23½ percent retained their placentae. Eighteen percent of the control cows died and 6 percent of the calves were lost. No difficulties occurred in the mineral-fed groups. At this same station, Knox, Benner, and Watkins (1941) studying the seasonal calcium and phosphorus requirements of range cattle noted that the addition of phosphorus supplements on New Mexico range usually increased the calf crop to above 90 percent with an average increase of 30 to 45 pounds in the weight of the calf at weaning time.

It is well known that milk production is a heavy drain upon the mineral supply of the body. Maynard (1947) stated that a cow producing 10,000 pounds of milk during her lactation secretes in it approximately 12 pounds of calcium and 10 pounds of phosphorus. He further stated that when the cow receives a ration deficient in phosphorus the body must supply this shortage leaving the animal in a depleted condition. Palmer et al. (1941) found that as a result of this deficiency ovulation is often suspended during the milking period. Upon cessation of lactation these workers concluded that the cow is able to slowly replace the phosphorus reserves and oestrum again occurs. Eckles et al. (1926) reported that the milk flow is eventually reduced by the lack of phosphorus in the feed.

Negative calcium and phosphorus balances seem to be the usual rather than the exeption during the early phase of lactation. In an extensive series of balance studies with dairy cattle, Forbes and associates (1917), (1918) and (1935) found that cows may be in negative balance with respect to these two elements and still conclude the lactation cycle in positive balance. The studies of Ellenberger, Newland, and Jones (1931) found that a mature Ayrshire cow lost calcium for 20 weeks after the onset of lactation and did not regain this loss until the forty-sixth week. This cow was in negative phosphorus balance for a period of twelve weeks followed by a storage which

which was accelerated as the milk flow decreased.

These negative balances do not necessarily indicate that a ration is deficient in these two elements. It would appear from these studies and those of Lamb et al. (1934) that the utilization of calcium and phosphorus reserves early in lactation is a normal process. All workers have observed that the losses of phosphorus in periods of negative balance are less than for calcium.

It has been conclusively demonstrated that the utilization of phosphorus in the ration is modified by many factors relating to the ration or to the environment. Most nutritionists agree that the chemical combinations in which phosphorus occurs in the diet, the presence of vitamins, the accessibility of light, the proportion of calcium and phosphorus depress or increase the utilization of phosphorus. The ratio of calcium to phosphorus in the dietary has been found to have an important influence upon the metabolism of both elements. If either is present in inadequate amounts, the other is not utilized properly even though it is present in normal quantities.

Early recommendations on the ratio of these two elements were based on the fact that they exist in ratios of 2 to 1 and 1.25 to 1 in the bone and milk respectively. McCollum and associates (1921) observed in their early studies that a ratio between calcium and phosphorus in the diet was perhaps of greater significance to the welfare of the animal than the absolute amounts of each. Meigs et al. (1926), using four lactating cows, suggested that an excess of calcium in the ration may interfere with the assimilation of phosphorus. These workers claimed that 2 parts by weight of calcium to 1 of phosphorus constituted an excess.

Haag, Jones, and Brandt (1932) indicated that a calcium-phosphorus ratio of 10.5 to 1 was no more detrimental than one of 7.6 to 1. Bethke, Kick and Wilder (1932) pointed out that for optimum growth and bone formation, a calcium-phosphorus ratio of 2 to 1 gave best results. Increasing the ratio of these two elements from 1 to 5 to 1 causes a progressive decrease in growth, bone ash, and the inorganic phosphate content of the blood. When the ration was changed to 1 to 0.25 growth was markedly depressed. Maynard (1947) stated that the desired ratio of these two elements is between 2 to 1 and 1 to 2, but that adequate nutrition is possible outside these limits. With adequate vitamin D in the ration, the ratio becomes of less importance.

An excellent review of literature on the aspects of vitamin D as related to calcium and phosphorus metabolism is given by Rupel, Bohstedt, and Hart (1933), Huffman and Duncan (1935), and Follis (1948). That calcium and phosphorus retention is markedly improved by the administration of vitamin D was conclusively shown by Hart and coworkers (1926), (1927), and (1929), Palmer and Gullickson (1935) and Wallis (1938). Rupel and coworkers (1933), in an extensive study of vitamin D with calves, found that a deficiency of this vitamin is manifested by a reduction in growth, progressive emaciation and deformity of the bones. They also noted that there was an accompanying reduction in the inorganic phosphorus content of the blood serum and in the percentage of total ash.

Animals which have been maintained for some time on a vitamin D deficient ration have been found to be in negative calcium and phosphorus balance. Detailed studies have proven that the ingestion of adequate amounts of this vitamin changes a negative balance to a positive one. The major portion of the calcium and phosphorus, even though absorbed, apparently is not retained by the body in the absence of this vitamin.

Schmidt and Greenberg (1935) stated that an excessive dosage will lead to a negative calcium and phosphorus balance either by action of vitamin D on the skeleton or as a result of the stimulating action of the latter on the parathyroid gland causing calcium and phosphorus to be withdrawn from the bones. A reversal was observed of the bone versus soft tissue preference for calcium and phosphorus in favor of the latter, particularly in the lumen of the large intestine so that excretion via this path is interfered with when excessive doses of vitamin D are administered.

Bohstedt (1942) asserted that calves may tolerate a rather large proportion of calcium to phosphorus. Studies on the vitamin D nutrition of the dairy calf by Rupel, Bohstedt, and Hart (1933) revealed that calves grew better on a calcium phosphorus ration of 3 to 1 than 1.5 to 1. The fact that a calf has a definite vitamin D requirement and suffers from a deficiency of this factor was demonstrated by these workers. They reported an improvement in the concentration of calcium and phosphorus in the blood plasma following vitamin D therapy of animals suffering from experimental rickets.

Wallis, Palmer, and Gullickson (1935) stated that the average calcium retention may be increased fourteen fold and the phosphorus retention eleven fold by vitamin D therapy. Increasing the mineral content of the ration of vitamin D deficient calves had no favorable effect or influence on the mineral retention. Vitamin D improved the mineral retention of calves suffering from a rachitic like syndrome within at least 3 to 7 weeks following therapy.

With the development of methods for the analysis of blood inorganic phosphate a valuable tool has been placed in the hands of experimenters because of its relationship to various problems of nutrition, metabolism and disease. The concentration of the inorganic phosphates of the blood of cattle as an aid in clinical diagnosis of aphosphorosis even before physical symptoms became apparent was first reported by the South African workers, Theiler, Green, and DuToit (1927). Even though the inorganic phosphate of the blood has been studied extensively in recent years as related to aphosphorosis in ruminants research workers are not in agreement as to the normal values for dairy and beef cattle.

A summary of the average blood inorganic phosphate content as found by

TABLE I.

CALCIUM AND INORGANIC PHOSPHORUS CONTENT OF NORMAL BOVINE BLOOD

INVESTIGATOR	INORGANIC PHOSPHORUS (mg./100 cc.)	BLOOD CONSTITUENT	CALCIUM (mg./100cc.)
Meigs, Blatherwick & Cary (1919)	5.38	Serum	10.38
Hart, et al. (1922)	3.94	"	16.25
Robinson & Huffman (1926)	5.87	"	11.00
Hayden & Fish (1928)	5.70	"	10.88
Anderson, Gayley & Pratt (1930)	4.46	"	12.63
Average, animals, all ages	3.62	"	13.31
Dukes (1947)	2.30-9.60	"	9.00-12.00
Theiler, Green, DuToit (1927)	5.20	Whole	-----
Malan, Green, DuToit (1928)	5.00	"	-----
Green & Macaskill (1928)	4.50	"	-----
Huffman, Duncan Robinson & Lamb (1933)			
Growing heifers	7.00-8.50	Plasma	-----
Mature cows	4.00-6.00	"	-----
Greaves, Maynard, Reeder (1934)	5.00	"	-----
Groenewald (1935)	5.10-7.20	"	8.15-10.30
Green & Macaskill (1928)	6.00	"	-----
Maynard (1947)	4.00-9.00	"	-----

the leading workers on the subject is given in Table I. In reviewing the extensive studies on the chemical composition of bovine blood, it should be noted whether analysis were made with whole blood or with blood serum or plasma. McVicar (1947) found that blood plasma values were higher than whole blood values by approximately 32 percent. In comparing values published by the South African workers, Green and Macaskill (1928), plasma determinations were found to be up to 25 percent higher than analysis on whole blood.

Black and associates (1942) found that symptoms of aphosphorosis developed in cattle grazing on a phosphorus-deficient range when the blood phosphorus content fell below 4 mg. per 100 ml. of whole blood. In contrast to this work, Knox, Benner and Watkins (1941) found that cows with blood plasma levels of from 2.00 to 3.00 mg. per cent phosphorus in winter and spring and from 3.00 to 4.50 mg. per cent in the summer were in excellent health. Huffman and others (1933) maintained that blood plasma phosphorus values lower than 4.00 mg. per cent are always suspicious, especially if the animal is less than one year of age. Greaves, Maynard, and Reeder (1934) gave 5.0 mg. per cent as the borderline value.

Palmer, Cunningham and Eckles (1930), in studying the variations in the inorganic phosphorus of the blood of dairy cattle found that exercise caused a marked change in the blood phosphate of cattle. At first there was a definite rise followed by a pronounced fall which persisted for several hours. Feeding had a small but significant effect on the inorganic phosphate in the blood. The values rose within the first hour and apparently did not return to normal until after about three hours. They also observed that parturition caused a decrease in inorganic phosphate which amounted to as much as 3.2 mg. per 100 cc. of plasma. The decrease was observed the day before calving, the lowest point occurring either before or after parturition.

Variations in the inorganic phosphate level of the blood due to changes in the phosphorus content of the ration, increasing age, pregnancy, and lactation have been reported by Meigs, et al. (1919). They found that the phosphorus blood levels were highly variable in the same animal from day to day. These workers reported that the feeding of from 4.5 to 6.9 grams of phosphorus daily as NaH_2PO_4 increased the inorganic phosphorus content of the blood plasma from 6.3 to 8.4 mg. percent.

In extensive calcium and phosphorus studies conducted by Henderson and Weakley (1930) with growing dairy cattle, a marked depression in the inorganic phosphate in the blood was observed within a week following the feeding of a low-phosphorus ration. Blood inorganic phosphorus values dropped to almost one-half and remained at that level throughout the experiment. These workers stated that the blood calcium levels remained the same which indicated that an animal could draw upon the bone for its calcium in order to keep the blood supply normal but that the animals were unable to do so for phosphorus, especially if there was insufficient calcium in the ration.

Jones and Mullen (1926) also observed a tendency of the inorganic phosphorus in the blood plasma of cattle to rise when phosphorus-rich supplements were added to the ration and a tendency to fall following the removal of the supplement. In studies involving the blood constituents of calves and their dams, Meigs, Blatherwick and Cary (1919) discovered that the inorganic phosphorus of the blood increased until about 6 months of age after which it decreased until the normal range for mature cattle was attained. Van Landingham, Henderson and Bowling (1935), studying the effect of age on the inorganic phosphate of whole blood, found that values tended to rise, reaching a peak at seven months of age and decreasing progressively to 24 months. Malan (1928) and Green and Macaskill (1928) found that the blood of new born calves contained twice as much inorganic phosphorus as their dam. This finding has been confirmed by Eckles, Gullickson and Palmer (1932).

The calcium content of the blood is ordinarily quite constant, but the content of inorganic phosphorus is quite variable. The factors that govern the inorganic phosphorus content of the blood are not fully understood. Calcium and phosphorus levels are strongly influenced by vitamin D and the parathyroid hormone as well as by the amount of each other present in the ration. The amounts of each element present in the blood depends upon a balance between the absorption from the ingested food, the excretion by way of the urine and feces and the storage and release from the skeleton and body tissues. Some 60 percent of the calcium in the blood is in a diffusible form and the remainder is quite nondiffusible, possibly attached to the serum albumin.

The feeding of phosphorus-rich supplements as a means of preventing aphosphorosis in ruminants has been advocated for some time. Numerous studies have been conducted relative to the phosphorus and calcium requirements of livestock under specific conditions. Maynard (1947) stated that the data as a whole were incomplete and so variable that it was very hazardous to draw conclusions as to the requirements for a given species over its entire period of growth. Beeson and associates (1941) found that the phosphorus requirements for growing and fattening steers under Idaho conditions was met by feeding rations containing 0.18 percent phosphorus, or a daily intake of 2.00 grams of feed phosphorus per 100 pounds of live weight. These investigators suggested that the minimum physiological phosphorus requirements is possibly nearer to 1.80 grams of feed phosphorus per 100 pounds of live weight.

In experimental studies at the Utah Station, Maynard et al. (1936) produced aphosphorosis in cattle on a phosphorus intake of 1.96 grams per 100 pounds of body weight. From the slaughter data of beef cattle of different ages and under different feeding regimes, Mitchell & McClure (1937) estimated that a 500 pound growing steer required a daily intake of 12.4 grams and a fattening steer of the same weight needed 16.7 grams. In a series of mineral balance studies with 1,000 pound steers, Forbes, French and Letonoff (1929) showed that a daily phosphorus intake of 10.84 grams was required to produce a positive balance of that element for maintenance.

Testimony is uniform to the effect that lactating cows and growing animals are most severely affected by a deficiency of available phosphorus in the ration. Huffman and associates (1933) found that the phosphorus requirement for milk production ranged from 0.5 to 0.7 grams of food phosphorus per pound of milk produced above the maintenance requirement. These figures were based on a 1,000 pound cow and 10 grams of phosphorus for maintenance. For a cow of the same weight and producing 30 pounds of 3.5 percent milk, Mitchell and McClure (1937) estimate that 26.6 grams of feed phosphorus per day is needed or 0.25 percent phosphorus on a dry ration basis.

Only a limited amount of work is available on which to estimate the requirements of a lactating cow under range conditions. In the extensive studies of Black and associates (1943), the feeding of 6.5 grams of phosphorus to dry cows and 14.3 grams to lactating cows proved highly beneficial in southern Texas. It therefore becomes quite evident that much work needs to be done with regard to the phosphorus requirements of cattle under conditions of the western range.

The supply of phosphorus to many of our farm animals comes entirely from pasturage and hay which is often low in this element. Mitchell (1947) stated that when the phosphorus content of herbage on a dry basis falls to about 0.12 percent or less, such roughage will not provide adequate phosphorus for the animal. This is in agreement with earlier studies made by Watkins (1937) at the New Mexico Station.

A recent report of the committee on Animal Nutrition of the National Research Council (1945) advised that cattle should be allowed free access to a phosphorus-rich mineral mixture if the forage is apt to fall much below 0.15

percent phosphorus on a dry matter basis. This committee recommends a range of from 12 grams of phosphorus per head daily for wintering weanling calves and yearlings to 24 grams for cows nursing calves. Stanley (1938), on the other hand, found that there was no beneficial effect of supplying a phosphorus supplement to cows on native pasture with an average phosphorus analysis of 0.176 percent. Body weight of cows, growth of calves, and blood analyses were used as a criterion in this study.

Since questions of mineral requirements have arisen in relation to western ranges, numerous studies have been made relative to the seasonal variation of the composition of range plants not only to locate phosphorus deficient areas, but to more intelligently supplement the range feeds at times of stress. Knowledge of the nutritive value of the native vegetation which abound throughout these areas and serves in many instances as the sole source of feed for a large percentage of range cattle is notably limited. Seasonal changes in the chemical composition of the most important range grasses has become one of our major nutritional studies.

In the phosphorus-deficient areas in Texas studied by Black and associates (1943) they found that 203 samples of forage contained only .076 percent phosphorus. Knox and others (1941) reported an average phosphorus content of .088 percent for 260 samples of native vegetation on the experimental range at the New Mexico Station. In both areas the forage did not contain adequate phosphorus to meet the requirements of range beef cattle which lends support to the contentions of Mitchell (1947).

Investigations relative to the nutritive value of the forage has revealed many significant findings. In studies in the Sacramento and San Joaquin valleys of California, Guilbert (1930) noted that the phosphorus content of the native grasses roughly parallels the protein content. Knox and Neale (1937), Stanley and Hodgson (1938), Stanley (1938), Black and associates

(1943), and Tash and Jones (1947) agreed that a low protein content of the forage is usually associated with a low phosphorus content and that the protein and phosphorus content of grasses tend to be lowest during winter and drouth periods when there is the least amount of green feed.

Knox, Benner and Watkins (1941) stated that abnormally large amounts of winter rain leached the grasses to such an extent that they became quite low in protein and phosphorus by early spring. They further stated that phosphorus deficiency is more severe and of longer duration than that of protein. Later studies by Watkins and Knox (1945) found that peak values for both protein and phosphorus occurred during either September or October at a time when the phosphorus requirements of beef breeding cattle were met largely by black gramma and mesa dropseed.

A correlation between the stage of maturity and the phosphorus content of grass has been reported by many writers. Morrison (1940) stated that during the early stages of growth, forage plants contained more calcium and phosphorus on a dry matter basis than that at later stages of growth. Immature grasses from closely grazed pasture were much higher in these minerals than the grasses allowed to mature for hay. Tash and Jones (1947) found that the shorter variety of grasses had a higher average phosphorus content than the taller grasses in the same period and at approximately the same stage of development. They also noted that palatable weeds contained more of this element than did grasses grown on the same soil.

Watkins and Knox (1945) observed that the value of annual weeds during winter and early spring when they became sufficiently large for grazing should not be underestimated. In studying the grazing habits of cattle in deficient areas of California, Guilbert (1930) noted that stock generally preferred to graze burned areas at least during the first season following a fire. Pure samples of these species were collected from both burned and unburned areas.

These samples were collected at various stages of maturity and during the dry season. At all stages of growth, the protein, nitrogen-free-extract and fiber content from corresponding samples were not found to be significantly different. However, a marked difference in the phosphorus content was observed. The samples from the burned areas contained from 25 to more than 100 percent more phosphorus than those from the unburned areas.

Black, Tash, Jones and Kleberg (1943) found that the phosphorus content of the forage increased following periods of heavy rainfall. They noted an increase in the phosphorus content of the blood of cattle grazing plants which had received abundant moisture as compared with the blood of cattle grazing during the dry seasons.

In the classical studies of Theiler, Green and DuToit (1924), it was found that a lack of adequate available phosphorus in the diet was manifested in a lack of appetite for normal food and the failure to utilize their food economically. Riddell, Hughes and Fitch (1927) and (1934), and Eckles and Bullickson (1927) disclosed that a lack of phosphorus did not lessen the digestibility of the ration, but it rearranged the metabolism so that the digestible nutrients were utilized inefficiently. The latter investigators concluded that cows on a low phosphorus diet required 20 percent more digestible nutrients to maintain live weight. That a phosphorus deficiency is a limiting factor in the economical utilization of feed was also noted by Kleiber, Goss and Guilbert (1936).

The effect of a phosphorus deficiency on the quality of beef has been reported by Hall, Mackintosh and Vail (1944) of the Kansas Station. They disclosed that beef from low-phosphorus steers was inferior to beef from high-phosphorus steers in palatability, keeping quality, and shrinkage loss. These studies revealed that fat tissue was more profoundly affected than muscle tissue by an inadequate plane of phosphorus nutrition. Rib roasts from the high-phosphorus steers were found to be more tender and juicy and have a more desirable flavor of lean and intensity of flavor of fat than the roasts from low-phosphorus steers. They were also found to have a more desirable aroma and a finer texture of lean.

The mere fact that a particular ration is rich in calcium or phosphorus does not necessarily mean that the consumption of this food will result in 100 percent absorption and assimilation. Various studies have shown that only 20 to 30 percent of the phosphorus and calcium ingested may be utilized. Forbes and Johnson (1937) stated that the feeding of rations containing the low phosphorus portion of plants may be responsible for many of the difficulties commonly attributed to the soil. Eckles, Gullickson and Palmer (1932) stated that although many of the phosphorus deficient cattle used in their experiments were from areas known to be deficient in available phosphorus, aphosphorosis may be produced experimentally by the feeding of low phosphorus feeds, especially during times of critical needs.

The profound physiological and anatomical disturbances occurring in cattle as a result of inadequate amounts of available phosphorus during the entire life span has been clearly demonstrated by repeated and widespread investigations. For practical economical livestock production, adequate provisions should be made to supply phosphorus when the soil and herbage is deficient in this element as shown by chemical analyses. The variability of the more pertinent findings reported in the literature regarding this worldwide deficiency indicates an urgent need for information upon which absolute recommendations might be made.

OBJECTIVES

This experiment was designed to determine the effect of different levels of mineral supplementation upon growth, certain blood constituents and reproduction in range beef cattle.

PROCEDURE

This experiment was initiated in January of 1947. Two areas of the State were selected for this study, one, 3 miles west of Wilburton (Latimer County) in south eastern Oklahoma and the other near Lake Carl Blackwell, 13 miles west of Stillwater (Payne County) in the north central part of the State.

At each experimental area 30 bred two-year-old grade Hereford heifers and 30 grade Hereford weanling heifer calves were placed on experiment. Each age group of heifers was divided in accordance with accepted experimental procedure into 3 uniform lots of ten head each. Part of the bred heifers at each location were purchased from C. A. Dean, Moorewood, Oklahoma, and part were produced in the experimental grade herd of Oklahoma A. and M. College. The weanling heifer calves at Wilburton were purchased from Gene Moore, Fairfax, Oklahoma, and those at Stillwater were produced in the Oklahoma A. and M. College experimental grade herd.

The rations fed corresponding lots at each area were essentially the same. The only ration difference between the lots at Stillwater and those at Wilburton was the source of prairie hay fed during the winter and the range herbage upon which the cattle grazed during the summer. These rations are shown in Table II. The hay fed at each area during the winter was produced in that local area on soils comparable to the soils of the pastures which the cattle grazed during the summer.

The cows and heifers in lot 1 in each area were fed no phosphorus other

TABLE II. RATIONS FED

WINTER	SUMMER
Bred Cows	
Lot I (10 head) - Inadequate Phosphorus. Prairie hay[1] Corn gluten meal[4] Ground rock salt, free choice Estimated phosphorus intake: 1 gm. per cwt.[2]	Pasture Ground rock salt, free choice
Lot II (10 head) - Probably Inadequate Phosphorus Prairie hay[1] Corn gluten meal[4] Ground rock salt, free choice Dicalcium phosphate to provide a total intake of 1½ gms. phosphorus per cwt.	Pasture Ground rock salt, free choice Dicalcium phosphate, if necessary to provide an estimated phosphorus intake of 1½ gms. per cwt.[3]
Lot III (10 head) - Adequate Phosphorus Prairie hay[1] Corn gluten meal[4] Ground rock salt, free choice Dicalcium phosphate to provide intake of 2½ gms. phosphorus per cwt.	Pasture Ground rock salt, free choice Mineral mixture, free choice (two parts salt and 1 part dicalcium phosphate)
Weanling Heifer Calves	
Lot I (10 head) - Inadequate Phosphorus Prairie hay[1] Corn gluten meal[4] Ground rock salt, free choice Estimated phosphorus intake: 1 gm. per cwt.[2]	Pasture Ground rock salt, free choice
Lot II (10 head) - Probably Inadequate Phosphorus Prairie hay[1] Corn gluten meal[4] Ground rock salt, free choice Dicalcium phosphate to provide a total intake of 1½ gms. phosphorus per cwt.	Pasture Ground rock salt, free choice Dicalcium phosphate, if necessary to provide an estimated phosphorus intake of 1½ gms. per cwt.[3]
Lot III (10 head) - Adequate Phosphorus Prairie hay[1] Corn gluten meal[4] Ground rock salt, free choice Dicalcium phosphate to provide a total intake of 2½ gms. phosphorus per cwt.	Pasture Ground rock salt, free choice Mineral mixture, free choice (two parts salt and 1 part dicalcium phosphate)

[1] Prairie hay was fed according to appetite.

[2] The phosphorus intake during the early part of the grazing season probably exceeded 1 gm. per cwt. but approached this level as the grass matured.

[3] The dicalcium phosphate was added to the salt.

[4] The corn gluten meal was fed at a level to provide sufficient protein for the various ages and weights of cattle.

than that present in the feeds and would be considered by many investigators as being maintained on a suboptimum phosphorus intake, particularly during the winter months. The only mineral supplement provided these animals was ground rock salt which was fed free choice.

The rations of the cows and heifers in lot 2 in each area were supplemented with dicalcium phosphate during the winter period so as to provide an estimated daily phosphorus intake of 1.5 grams per hundred pounds of body weight. The amount of mineral fed during this period was adjusted each weigh day to compensate for gains or losses in weight. When chemical analyses indicated that the phosphorus of the herbage had dropped below levels generally considered by most investigators as barely capable of maintaining the phosphorus nutrition of the animal, some phosphorus was supplied in the salt. Only enough dicalcium phosphate was added to the salt to supply an estimated total daily intake of approximately 1.5 grams of phosphorus per 100 pounds of body weight. In most instances a mixture of 1 part of mineral to 9 parts of salt was adequate to meet the above level.

The rations of the cows and heifers in lot 3 were supplemented with enough dicalcium phosphate to supply 2.5 grams of phosphorus per hundredweight during the winter, this amount being considered an adequate intake. During the summer the cattle of these lots were allowed free access to a mixture of 3 parts salt and 1 part dicalcium phosphate.

Corn gluten meal was fed to all lots during the winter because it is a low-phosphorus protein supplement.

All lots were confined to traps and hand fed during the five winter months. During the summer (seven months), the cattle were allowed to graze native pasture. A minimum of 10 acres per head was allowed during the grazing season which insured an adequate quantity of herbage. To eliminate the effect of any variation between pastures the cattle were rotated among pastures each two-week period. The cows were pasture bred to high quality purebred Hereford bulls. During the breeding season the bulls were rotated among the lots of heifers every two weeks. Such a procedure favored equal dames for conception and likewise tended to equalize the influence of any one bull on a particular lot in so far as heredity might affect the size of calves at either birth or weaning. The bulls were put to pasture May 1st and taken out about the 1st of September.

The heifer calves from the first calf crop were retained in the experimental herd and given the same feeds as their dams. The bull calves were castrated and allowed to run with their dams until October at which time they were weaned and full fed for approximately 190 days. All calves were dehorned with hot bell irons and established practices for controlling parasites and dieseases were followed.

The level of the blood plasma inorganic phosphorus was taken as one measure of the phosphorus nutrition of the cattle. Blood samples from the jugular vein were collected in lithium citrated tubes from each individual at the onset of the experiment and at intervals of from 30 to 60 days thereafter. These samples were kept under refrigeration and the blood plasma analyzed for inorganic phosphorus (Fiske and Subbarow (1925), calcium (Clark and Collip (1925) and carotene (Kimble (1939) by the Department of Agriculture Chemistry. Colormetric determinations of the percent of hemoglobin and the number of red blood cells were also made. This indirect method of determining the number of red blood cells was correlated with direct microscopic counts. All blood analyses were statistically treated by the analysis of variance method of Snedecor (1946).

All animals were weighed at approximately thirty-day intervals. The calves were weighed as soon after birth as possible and at weaning time.

Representative samples of the predominant species of native grasses were collected from each pasture in the two areas to determine the crude protein, calcium and inorganic phosphorus content. These samples were obtained by clipping the plant 1 to 2 inches above the ground. Only those plants which had not been previously clipped or grazed were collected. Periodic analyses were made of all feeds for major feed nutrients by the Department of Agricultural Chemistry Research. Soil samples from both areas were analyzed by the Department of Agronomy for acidity, calcium, soluble phosphorus, nitrogen, iron manganese and magnesium.

The following records were kept:

1. Weights.
2. Blood analyses.
3. Reproduction data.
4. Feed consumption.
5. Observations of the state of health.
6. Feed analyses.
7. Soil analyses.

RESULTS

PART I. WILBURTON STATION

SOIL ANALYSIS AND PREDOMINATE GRASSES

Soil analyses at the experimental range west of Wilburton, Oklahoma, showed that the soil was strongly acid and very low in soluble phosphates. The soil class varied from a Vilonia silt loam and a Choteau very fine, brown, sandy loam to a Pottsville stony loam. The predominate species of grass were Big and Little Bluestem, Indian and Joint Grass.

FEED ANALYSIS

The protein, calcium and phosphorus content of the rations fed is given in Table III.

RAINFALL DATA

The average monthly rainfall at the Wilburton Station is presented in Table IV.

BLOOD ANALYSIS

The composition of the blood plasma of the cows and heifers is shown in Tables V and VI respectively. It will be noted that the average inorganic phosphorus content of the blood plasma of the cows was 7.1 mg. per 100 ml. of plasma at the beginning of the experiment and that of the heifers varied from 7.7 to 8.2 mg. per 100 ml. of blood plasma. The average inorganic phosphorus values of all lots of cows decreased from the beginning of the experiment to April 4, 1947. The average value of inorganic phosphorus in the plasma of the

TABLE III.

Composition of feeds used at Wilburton

Item	Date of Sample	Protein	Phosphorus	Calcium
		%	%	%
Dicalcium phosphate	11-5-46	-----	18.700	23.200
Corn gluten meal	11-7-46	49.75	0.383	0.133
Corn gluten meal	11-17-47	49.00	0.418	0.190
Prairie hay	11-9-46	4.22	0.060	0.460
Prairie hay	9-28-47	5.03	0.064	0.410
Prairie hay	11-21-47	5.27	0.069	0.660
Pasture	4-28-47	12.02	0.176	0.490
Pasture	6-4-47	8.19	0.095	0.390
Pasture	8-26-47	4.08	0.031	0.430
Pasture	11-21-47	3.04	0.030	0.450

TABLE IV.

Average monthly rainfall at Wilburton

Month	Average Rainfall
	inches
January 1947	0.90
February	0.18
March	2.18
April	9.22
May	7.38
June	5.05
July	0.86
August	0.98
September	4.11
October	3.13
November	2.64
December	5.88
January 1948	0.85
February	4.46
March	2.95
April	0.71

TABLE V.

Blood analyses of cows at Wilburton
(Average for all cows of each lot.)

Lots	Winter period		Summer period				Winter period			Summer period
Date bled	2/3/47	4/27/47	6/27/47	8/27/47	9/28/47	11/24/47	12/31/47	2/2/48	4/16/48	6/1/48
			(1) Phosphorus (mg./100 ml. plasma)							
Lot 1	7.1	4.8**	4.5	3.4	2.4	2.5	1.9**	1.8**	1.8**	2.8**
Lot 2	7.1	6.2	4.5	3.5	2.5	2.1	5.4	5.0	5.3	4.7
Lot 3	7.1	6.6	4.1	3.8	2.9	2.6	7.4	5.9	6.5	4.1
			(2) Calcium (mg./100 ml. plasma)							
Lot 1	10.3	10.5	11.6	11.5	11.9	11.8	11.8	12.3	11.5	11.3
Lot 2	10.4	10.4	10.6	10.6	11.3	11.1	11.7	11.6	11.4	10.6
Lot 3	10.7	10.4	10.8	10.6	11.8	10.8	10.1	11.2	10.7	10.3
			(3) Carotene (micrograms/100 ml. plasma)							
Lot 1	128.2	314.2	772.6	450.2	455.0	686.4	241.7	185.9	427.3	675.0
Lot 2	112.4	258.5	717.7	433.1	394.9*	534.2*	214.4	200.2	334.8	475.0
Lot 3	104.8	301.2	651.2*	383.2*	449.3	572.9	179.1*	182.3	350.7	441.4**
			(4) Hemoglobin (percent)							
						9.8	10.0	10.0	9.9	9.8
						9.7	10.0	9.8	9.2	9.7
						9.8	9.9	9.5	9.1	9.4
			(5) Red blood cells (thousands/cu. mm.)							
Lot 1						5,112	5,422	6,075	6,685	5,908
Lot 2						5,280	5,327	5,930	6,120	5,940
Lot 3						5,262	5,192	5,993	5,832	5,843

* Significant at the 5% level.
**Significant at the 1% level.

TABLE VI

Blood analyses of heifers at Wilburton
(Average for all heifers of each lot.)

Lots	Winter period		Summer period				Winter period			Summer period
Date bled	2/3/47	4/27/47	6/27/47	8/27/47	9/28/47	11/24/47	12/31/47	2/2/48	4/16/48	6/1/48
			(1) Phosphorus (mg/100 ml. plasma)							
Lot 1	7.7	5.4	6.9	4.5	4.3	3.8	2.8**	2.7**	3.2**	5.4
Lot 2	8.2	7.0	6.3	4.3	4.3	3.5	5.5	5.4	5.5	5.7
Lot 3	8.2	8.6	6.3	5.2	5.3	3.4	8.2	7.1	6.6	4.7
			(2) Calcium (mg./100 ml. plasma)							
Lot 1	10.1	10.5	10.6	11.6	11.6	11.7	11.6	12.6	12.2	10.9
Lot 2	10.5	10.9	11.5	11.7	11.5	11.6	11.6	12.2	12.0	10.6
Lot 3	10.3	10.2	11.1	11.5	11.3	11.4	10.4	12.4	10.4	10.3
			(3) Carotene (micrograms/100 ml. plasma)							
Lot 1	105.7	274.3	558.8	380.2	447.4	705.7	242.4	133.3	399.8	573.0
Lot 2	98.1	279.4	380.0**	320.9	422.3	571.2	226.4	153.6	266.7	253.2**
Lot 3	91.2	309.7	570.1	337.1	438.5	552.2**	184.0	168.1	343.9	307.7
			(4) Hemoglobin (percent)							
Lot 1						9.7	9.9	9.7	9.6	9.9
Lot 2						9.4	9.8	10.4	9.6	9.7
Lot 3						10.6	9.9	10.0	9.4	9.9
			(5) Red blood cells (thousands/cu. mm.)							
Lot 1						5,572	5,372	6,540	6,465	5,728
Lot 2						5,380	5,182	6,455	6,315	5,648
Lot 3						5,950	5,350	6,402	6,242	5,928

* Significant at the 5% level.
** Significant at the 1% level.

cows of lot 1 was considerably lower than the other two lots and this difference was significant at the 1% level. The values for all lots of cows declined throughout the first summer season. During August, 1947, the average inorganic phosphorus level of lots 1, 2 and 3 were 2.4, 2.5 and 2.9 mg. per 100 ml. of blood plasma, respectively. The values for the respective lots in November were 2.5, 2.1 and 2.6 mg. The addition of dicalcium phosphate to the salt provided the cows of lot 3 did not significantly alter the level of inorganic plasma phosphorus during the summer.

During the winter of 1947-48, the average level of inorganic phosphorus of the cows of lot 1 was never higher than 1.9 mg. percent whereas the average level for the lot 3 cows was never below 5.9 mg. percent. The phosphorus level of the lot 2 cows ranged from 5.0 to 5.4 mg. percent. The variation between lots for the December, February and April bleedings was significant at the 1% level of probability.

When turned to pasture in the spring of 1948, the cows in lot 1 showed an increase of 1 mg. percent of plasma phosphorus while the level of the lot 2 and lot 3 cows tended to decrease. With the exception of the bleeding of June, 1947, the lot 3 cows were consistently higher than the other two lots in inorganic plasma phosphorus. The lot 1 cows were consistently the lowest except during June and November of 1947.

The inorganic plasma phosphorus levels of the heifers used in this experiment did not follow a definite trend during the first winter and summer periods. However, during the winter of 1947-48 the average levels of phosphorus of the heifers of lot 1 were consistently below that of the other lots and the differences between lots were significant at the 1% level of probability. When turned to pasture in the spring of 1948, the lot 1 and lot 2 heifers showed an increase in the plasma phosphorus content while those in lot 3 exhibited a marked decrease.

The blood calcium levels in both cows and heifers showed only slight fluctuations throughout the course of this study. All values were within the accepted normal range. The average calcium content of the blood plasma of the cows ranged from 10.3 to 12.3 mg. percent while the plasma calcium averages of the heifers ranged from 10.1 to 12.6 mg. percent.

All carotene values for both the cows and heifers were within accepted normal limits tending to be the lowest during periods of low dietary carotene intake. Although statistically significant differences were observed between lots, no definite trend was indicated for any particular lot or lots.

There were no consistent differences in the hemoglobin content of the blood samples taken from the various lots of cattle. The number of red blood cells of all lots were within an accepted normal range and no consistent variation was found.

ABNORMALITIES

Physical symptoms of aphosphorosis were evident in some cows of lots 1 and 2. These symptoms were evident only in those cows nursing calves. Cow #134 of the control lot 1 was the first cow to exhibit definite symptoms of a phosphorus deficiency. This cow lost considerable body weight while nursing a large heifer calf during most of the first winter period and the summer period which followed. She reached a low weight of 493 pounds during the month of August, 1947. Following the weaning of her calf in October, 1947, she gained only a few pounds and then showed a slight decline in weight the first few weeks on the low-phosphorus winter diet. From August, 1947, to the end of the second winter period, April 16, 1948, her plasma inorganic phosphorus was below 2.0 mg. per 100 ml.

Early in the 1947 summer period, this cow became noticeably stiff in the joints, particularly in the shoulders, and exhibited a "creepy", unsteady gait. She moved about with considerable difficulty. Excessive hoof growth was also noted as well as nervousness which became apparent following the onset of the second winter season. This cow was never observed in heat during the summer of 1947, and failed to produce a calf the following spring, lending support to the theory that cows in advanced stages of aphosphorosis cease to have an oestrum. When turned to grass in the spring of 1948, she gained some weight but still moved about with a "creepy", stiff gait. Cows 169 and 158, also in the low-phosphorus group, exhibited similar symptoms.

Practical symptoms of a phosphorus deficiency were not noted in the heifers in lot 1. They were consistently the poorest lot in so far as body weight, thriftiness and general appearance were concerned. The addition of phosphorus in the form of dicalcium phosphate to the salt of the heifers of lots 2 and 3 during the second winter period resulted not only in an increased blood phosphorus level but also in increased weight and improved general appearance as well.

A lack of appetite was not noted in any of the low-phosphorus lots. However, the chewing of sticks and bark was noted in several instances. During the winter period of 1947-48, the cows of lot 1 chewed the bark from the trees and fence posts. Bark chewing was also evident among the lot 2 cows.

FEED CONSUMPTION

The average feed consumption of all lots is given in Table VII. No significant differences were noted in the feed consumption among the three lots of heifers and cows. The lot 1 cows and lot 1 heifers, however, consumed slightly less prairie hay during both winter periods than did the other

TABLE VII

Feed consumption of cows and heifers at Wilburton

	Cows			Heifers		
	Lot 1	Lot 2	Lot 3	Lot 1	Lot 2	Lot 3
Number of animals per lot	10	10	10	10	10	10
Total gain or loss per head (1/31/47 to 4/16/48)						
Average daily ration (lbs):						
1. Winter period (2/16/47 to 4/26/47)						
Prairie hay	12.98	13.22	13.14	8.30	8.87	8.63
Corn gluten meal	1.25	1.25	1.25	1.25	1.25	1.25
Ground rock salt	0.09	0.09	0.07	0.05	0.03	0.04
Dicalcium phosphate	----	0.04	0.12	----	0.01	0.06
Calcium intake (gms/cwt)	4.23	4.98	6.42	4.26	4.84	5.89
Phosphorus intake (gms/cwt)	0.93	1.48	2.61	1.10	1.48	2.41
Ca/P ratio	4.5:1	3.6:1	2.5:1	3.8:1	3.3:1	2.5:1
2. Summer period (4/26/47 to 11/22/47)						
Native pasture	ad lib	ad lib	ad lib	ad lib	ad lib	ad lib
Ground rock salt	0.05	0.05	0.05	0.04	0.04	0.03
Dicalcium phosphate	----	0.0005	0.01	----	0.0005	0.003
3. Winter period (11/22/47 to 4/16/48)						
Prairie hay	16.00	17.26	17.03	15.18	15.76	16.48
Corn gluten meal	1.23	1.23	1.23	1.23	1.23	1.23
Ground rock salt	0.10	0.05	0.05	0.02	0.03	0.03
Dicalcium phosphate	----	0.05	0.12	----	0.03	0.12
Calcium intake (gms/cwt)	4.32	4.95	6.18	4.77	5.41	6.23
Phosphorus intake (gms/cwt)	1.08	1.60	2.52	1.21	1.61	2.56
Ca/P ratio	4:1	3.1:1	2.5:1	3.9:1	3.3:1	2.4:1
Feed per cwt gain*						
Prairie hay	-----	-----	-----	1317	1134	900
Corn gluten meal	-----	-----	-----	126	99	80
Ground rock salt	-----	-----	-----	7	6	4
Dicalcium phosphate	-----	-----	-----	----	2	7

* The feed per cwt. gain for the cows was not included because most of the cows that calved during the winter showed a loss in weight due to parturition.

lots. The calcium-phosphorus ratio based on average consumption figures for all lots ranged from 4.5 to 2.4 to 1, the wider ratios being observed in lot 1 in each instance.

The heifers of lot 3 on the high phosphorus intake made greater use of their feed than did either of the low intake groups as evidenced by the feed requirements per 100 pounds of gain. The lot 1 heifers required considerably more feed per 100 pounds of gain than did those of lot 2.

The summary of data on weights and calf crops is given in Table VIII. Gains to June 1, 1948, show that the lot 1 cows gained only 36.5 pounds as compared with gains of 133.9 and 130.0 pounds for lot 2 and lot 3 respectively. The summary data on weight of the three lots of heifers if presented in Table IX. The average gain of the heifers to the same date was 292.6 pounds for lot 1, 368.5 for lot 2 and 413 pounds for lot 3.

REPRODUCTION

From the summary data included in Table VIII, the low percentage calf crop given for the first breeding season cannot be attributed to differences in treatment. Only slight differences were noted in the birth weight of calves. During the second breeding season the heaviest calves were produced by cows in lot 3.

Only three cows in lot 1 calved each season. One of these cows lost her calf at birth the first year. Five of the cows that calved the first year failed to reproduce the second year. Of the 5 cows that calved the first year in lot 2, three produced calves the second year, one of which was dead at birth. Two other cows in this lot gave birth to premature calves. Of the seven cows that calved in lot 3 the first year, five failed to reproduce the following season. Cow #138 of lot 3 lost her calf the first year but produced a normal calf the next year. Cow #175 of lot 3 did not produce a calf her first year,

TABLE VIII

Summary of data on weights and calf crop at Wilburton

	Lot 1	Lot 2	Lot 3
Cows:			
1947			
Number per lot	10	10	10
Date project began	1/31/47	1/31/47	1/31/47
Av. initial weights	653.5	653.5	653.5
Date summer began	4/27/47	4/27/47	4/27/47
Av. wt. per cow, beginning summer period	606.0	604.5	597.0
Date summer period ended	11/22/47	11/22/47	11/22/47
Av. wt. per cow end of summer	693.2	736.0	685.3
Av. gain during summer period	87.2	131.5	88.3
Number of calves born, 1947	7	5	8
Number of calves weaned	7	5	7
Percent of calf crop	70	50	80
Percent calf crop weaned of those born	100	100	87.5
Av. birth wt. per calf	57.0	55.0	56.5
Av. weaning wt. per calf	318.0	302.0	305.3
Av. wt. per cow, weaning date	658.4	709.2	673.7
Av. gain per cow during lactation	4.9	55.7	20.2
1948			
Date winter period began	11/22/47	11/22/47	11/22/47
Av. wt. beginning winter period	693.2	736.0	685.3
Number of calves born	5	6	4
Percent of calf crop	50	60	40
Av. birth wt. of calf	67.2	64	77
Date winter period ended	4/16/48	4/16/48	4/16/48
Av. gain or loss winter period	-68.5	-11.9	+36.2
Av. wt. per cow, 6/1/48	690.0	787.4	783.5
Av. gain 6-1-48	36.5	133.9	130.0

TABLE IX

Summary of data on weights of heifers at Wilburton

	Lot 1	Lot 2	Lot 3
Number per lot	10	10	10
Date project began	1/31/47	1/31/47	1/31/47
Av. initial wts.	382.5	382.5	382.5
Date winter period ended	4/27/47	4/27/47	4/27/47
Av. wt. end winter period	429.5	424.5	441.0
Av. gain or loss during winter period	+47.0	+42.0	+58.5
Date summer period ended	11/22/47	11/22/47	11/22/47
Av. wt. end summer period	578.5	600.8	656.0
Av. gain summer period	149.0	176.3	215.0
Av. wt. end winter period	594.9	653.1	717.0
Av. gain or loss winter	15.5	52.3	105.3
Date summer period began	4/16/48	4/16/48	4/16/48
Av. wt. 6-1-48	675.1	75.10	795.0
Av. gain to 6-1-48	292.6	366.5	413.0

and in the spring of 1948 lost her calf at one day of age. The calf was normal when born. A cold freezing rain started soon after the calf was born and death was attributed to chilling.

PART II. STILLWATER STATION

SOIL ANALYSIS

The soils of the Lake Carl Blackwell area were found to border upon a phosphorus deficiency. The soil class varied from a Renfrow clay loam to a Zaneis fine, sandy loam. The predominant species of range grasses were Big and little Bluestem, Indian, Dropseed, Buffalo and Switch Grass.

FEED ANALYSIS

The average protein, calcium and phosphorus content of the native vegetation and other components of the experimental ration is given in Table X.

RAINFALL

The average monthly rainfall at the Lake Carl Blackwell area is presented in Table XI.

BLOOD ANALYSIS

The average analyses of the blood plasma constituents is given in Tables XII and XIII for the cows and heifers respectively. It will be noted that the average inorganic phosphorus content of the initial blood samples taken before supplementation was significantly lower for lot 1 than the average of the other two lots. No explanation is offered for this since they were allotted as uniformly as possible taking into consideration weights and

TABLE X

Feed analysis at Stillwater

Item	Date of Sample	Protein	Phosphorus	Calcium
		%	%	%
Dicalcium phosphate	11- 5-46	-----	18.700	23.200
Corn gluten meal	11- 7-46	49.75	0.383	0.133
Corn gluten meal	11-17-47	49.00	0.418	0.190
Prairie hay	1-16-47	3.74	0.062	0.450
Prairie hay	10-14-47	3.99	0.055	0.460
Prairie hay	11-17-47	3.84	0.054	0.400
Prairie hay	11-19-47	3.94	0.069	0.388
Pasture	6-17-47	8.60	0.115	0.390

TABLE XI

Average monthly rainfall at Stillwater

Month	Average rainfall in inches
January 1947	0.65
February	0.23
March	0.75
April	11.06
May	6.79
June	2.20
July	3.20
August	0.20
September	1.68
October	0.28
November	1.51
December	1.35
January 1948	1.30
February	3.98
March	3.13
April	3.41

genetic background. The first bleeding was made after they were allotted. During the second winter period as well as during November, 1947, the lot 1 cows had the lowest plasma phosphorus value at all bleedings reaching a low of 2.8 mg. percent in March, 1948. The variation between lots was significant at the 1% level during November, February and March, and at the 5% level during April. The lot 3 cows receiving the highest plane of phosphorus nutrition were consistently higher in plasma phosphorus.

The same general pattern was observed in the average plasma phosphorus content of the three lots of heifers. During the second winter period, the lot 1 heifers had consistently lower plasma phosphorus values than the other two lots and the variation between lots was significant at the 1% level.

Examination of the average plasma calcium levels revealed that values throughout the period remained within the normal range for cattle. Average values ranged from 9.9 to 11.8 mg. percent for the cows and 9.9 to 12.5 mg. percent for the heifers. At the close of the winter period, April, 1948, the lot 3 heifers had significantly lower values than did the other lots.

The plasma carotene levels of both heifers and cows were extremely low during the latter part of the winter period of 1947-48. In view of the fact that carotene content of the prairie hay fed was low it seemed advisable to feed a carotene mix so as to provide all lots of cows with a minimum of 92,000 I. U. daily. The increase in the plasma carotene values for April, 1948, was due to the small amount of green grass consumed which could be found in the winter traps as well as to the carotene mix fed from February 10th, to March 17, 1948. The heifers were found to have the lowest level of this blood constituent during the second winter period, values as low as 50.6 micrograms per 100 ml. of plasma being observed.

Only slight differences were noted in the percent of hemoglobin among the three lots of cows and heifers. There were no large variations in the

TABLE XII

Blood analyses of cows at Stillwater
(Average for all cows of each lot)

	Winter period		Summer period			Winter period			Summer period
Date bled	2/11/47	4/17/47	6/2/47	10/7/47	11/4/47	2/2/48	3/18/48	4/22/48	6/9/48
			(1) Phosphorus (mgs./100 ml. plasma)						
Lot 1	4.2**	6.2*	4.1	5.5	3.3**	3.2**	2.8**	3.4	4.3
Lot 2	6.1	7.3	4.2	4.5	5.0	4.4	5.8	6.3	4.7
Lot 3	7.6	8.0	4.2	4.6	6.7	6.1	5.9	5.4	4.6
			(2) Calcium (mgs./100 ml. plasma)						
Lot 1	11.2	9.8	11.6	11.8	11.0	11.2	10.9	10.5	9.9
Lot 2	11.1	9.4	11.8	11.6	11.1	10.9	11.2	10.4	10.2
Lot 3	11.1	9.7	11.2	11.7	10.7	11.0	11.7	11.3	10.6
			(3) Carotene (micrograms/100 ml. plasma)						
Lot 1	90.8	260.7	1031.1	280.5	213.6	76.5	74.0	278.0	746.4
Lot 2	99.9	195.9	818.5*	318.2	300.3	72.1	84.6	284.0	734.2
Lot 3	121.9	200.4	986.2	325.5	284.1	68.0	74.7	339.0	865.5
			(4) Hemoglobin (percent)						
Lot 1				9.7	9.5	10.0	9.3	8.8	9.5
Lot 2				9.1	9.3	9.9	9.8	9.5	9.7
Lot 3				9.0	9.3	9.8	9.6	9.2	9.8
			(5) Red blood cells (thousands/cu. mm.)						
Lot 1				6,168	5,420	6,775	5,983	5,719	5,827
Lot 2				5,545	5,295	6,770	6,310	6,128	6,027
Lot 3				5,669	5,192	6,818	6,110	5,898	5,907

* Significant at the 5% level.
** Significant at the 1% level.

TABLE XIII

Blood analyses of heifers at Stillwater
(Average for all heifers of each lot.)

	Winter period		Summer period			Winter period			Summer period
Date bled	2/11/47	4/17/47	6/2/47	10/47/47	11/4/47	2/2/48	3/18/48	4/22/48	6/9/48
(1) Phosphorus (mg./100 ml. plasma)									
Lot 1	5.9	4.7**		6.0	5.0	3.5**	3.9**	3.9**	6.0
Lot 2	6.3	6.6		6.1	5.2	4.9	6.3	5.8	5.5
Lot 3	6.6	7.3		6.0	5.2	6.4	7.4	7.0	5.4
(2) Calcium (mg./100 ml. plasma)									
Lot 1	11.0	10.5		11.8	11.3	10.9	11.3	12.5	10.6
Lot 2	11.4	10.2		11.8	11.5	10.8	11.3	10.8	10.5
Lot 3	11.3	9.7		11.9	11.4	10.2	11.0	9.9*	11.0
(3) Carotene (micrograms/100 ml. plasma)									
Lot 1	78.2	163.9		289.9	251.2	55.1	54.4	277.0	667.9
Lot 2	80.6	192.5		264.1	260.7	57.7	65.5	263.0	734.2
Lot 3	81.5	172.6		238.3	319.4	62.3	50.6	293.0	692.9
(4) Hemoglobin (percent)									
Lot 1				8.7	9.5	10.0	9.7	10.0	9.7
Lot 2				8.3	9.4	9.8	9.6	9.8	9.8
Lot 3				8.8	9.3	9.9	10.0	9.4	9.6
(5) Red blood cells (thousands/cu. mm.)									
Lot 1				5,471	5,282	6,915	6,193	6,490	5,960
Lot 2				5,193	5,110	6,802	6,128	6,193	6,067
Lot 3				5,679	5,112	6,852	5,653	6,032	5,997

* Significant at the 5% level
** Significant at the 1% level

number of red blood cells of the cattle of this experiment.

ABNORMALITIES

Symptoms of a phosphorus deficiency were observed in cow #137 of lot 1 during the early part of the second winter period. Some stiffness was noted in the front legs and shoulders. No physical symptoms of any deficiency were observed in any of the heifers. Cow #171 in lot 2 refused to eat the corn gluten meal when mixed with the mineral supplement.

FEED CONSUMPTION

The average feed consumption and feed per hundred pounds of gain is given in Table XIV. During the first winter period, it was observed that the lot 1 cows and lot 1 heifers consumed slightly more hay than the other lots. The lot 3 heifers consumed slightly less prairie hay during the second winter than did the other lots. The calcium-phosphorus ratios in all groups ranged from 4.6 to 1.9 to 1.

All lots of cows showed losses from the start of the experiment to the conclusion of the second winter period. The lot 1 heifers gained 264.5 pounds as against 273.5 for lot 2 and 308.0 for lot 3. Providing 2.5 grams of feed phosphorus per hundredweight daily resulted in a greater net gain for the 441 days as well as more efficient use of the feed as evidenced by the amount of feed required to produce 100 pounds of gain.

The summary data on weights and calf crops are presented in Table XV. The lot 1 cows gained 19.0 pounds from the start of the experiment to June, 1948, while the lot 2 cows gained 5.5 pounds and those of lot 3 gained 71.0 pounds. These gains are lower than those observed in the cows at the Wilburton Station which is due presumeably to the fact that nearly all of the cows

TABLE XIV

Feed consumption of cows and heifers at Stillwater

	Cows			Heifers		
	Lot 1	Lot 2	Lot 3	Lot 1	Lot 2	Lot 3
Number of animals per lot	10	10	10	10	10	10
Total gain or loss per head (2/5/47 to 4/21/48)	-116.5	-93.5	-98.0	+264.5	+273.5	+308.0
Average daily ration (lbs):						
1. Winter period (2/5/47 to 4/34/47)						
Prairie hay	13.96	13.75	13.92	8.36	8.22	8.34
Corn gluten meal	1.38	1.38	1.38	1.38	1.38	1.38
Ground rock salt	0.03	0.03	0.03	0.03	0.03	0.03
Dicalcium phosphate	----	0.06	0.16	----	0.02	0.02
Calcium intake (gms/cwt)	4.06	5.04	4.95	2.52	4.40	6.50
Phosphorus intake (gms/cwt)	0.89	1.67	2.68	0.70	1.43	2.60
Ca/P ratio	4.6:1	3.1:1	2.3:1	3.8:1	3.1:1	3.1:1
2. Summer period (4/27/47 to 11/3/47)						
Native pasture	ad lib	ad lib	ad lib	ad lib	ad lib	ad lib
Ground rock salt	0.03	0.04	0.04	0.02	0.02	0.03
Dicalcium phosphate	----	0.0007	0.005	----	0.007	0.003
3. Winter period (11/3/47 to 4/21/48)						
Prairie hay	14.51	15.13	14.92	12.73	12.90	12.64
Corn gluten meal	1.22	1.22	1.22	1.22	1.22	1.22
Ground rock salt	0.06	0.04	0.06	0.05	0.06	0.04
Dicalcium phosphate	----	0.07	0.16	----	0.06	0.14
Calcium intake (gms/cwt)	3.52	4.33	5.50	4.70	4.72	6.51
Phosphorus intake (gms/cwt)	0.76	1.41	2.40	1.03	1.60	2.61
Ca/P ratio	4.6:1	3.1:1	1.9:1	4.4:1	2.9:1	2.3:1
Feed per cwt gain*						
Prairie hay	----	----	----	1065	1036	909
Corn gluten meal	----	----	----	119	115	102
Ground rock salt	----	----	----	6	6	6
Dicalcium phosphate	----	----	----	----	5	9

* The feed per cwt. gain for the cows was not included because most of the cows that calved during the winter showed a loss in weight due to parturition.

at Stillwater produced a calf each season. The summary data on the weights of the three lots of heifers are given in Table XVI. The lot 3 heifers gained a total of 453.5 pounds while lots 1 and 2 gained 415.5 and 410.5, respectively, during this same period.

REPRODUCTION

No difficulties in the breeding efficiency of the three lots of cows were noted. During the first breeding season, 29 of the 30 head of cows produced calves and all of these calves were alive at weaning time. The following breeding season, 22 calves were born in the three lots of cows. No significant difference in the birth weight of the calves was noted during the first season. However, the calves from the lot 3 cows were the lightest at birth during the second calving season. There was a decided difference in the weaning weight of the calves in favor of the lot 2 cows. The calves produced by the lot 3 cows were slightly lighter than those from the lot 1 cows. The cows in lot 3 were in better condition at weaning time than were the remaining two lots.

PART III. STEERS PRODUCED FROM COWS AT STILLWATER AND WILBURTON

The twenty-seven head of steers produced by the cows at both stations were full fed for 197 days in a large lot on the Wilburton experimental area. They were self fed ground milo and hand fed weighed amounts of prairie hay and cottonseed meal, daily. Some whole oats were fed to start the steers on feed. They were allowed free access to a mixture of ground rock salt and ground limestone which was provided in separate boxes. The average feed consumption and the feed required to produce 100 pounds of gain is presented in Table XVII. The steers were placed on feed October 14, 1947, at which time

TABLE XV

Summary of data on weights and calf crop at Stillwater

	Lot 1	Lot 2	Lot 3
Cows:			
1947			
Number per lot	10	10	10
Date project began	1/31/47	1/31/47	1/31/47
Av. initial weights	820.5	820.0	820.0
Date summer period began	4/24/47	4/24/47	4/24/47
Av. wt. per cow, beginning summer period	655.0	657.0	666.5
Date summer period ended	11/3/47	11/3/47	11/3/47
Av. wt. per cow, end of summer period	847.5	826.0	857.0
Av. gain during summer period	182.5	169.0	190.5
Number of calves born, 1947	10	9	10
Number of calves weaned	10	9	10
Percent of calf crop	100	100	100
Percent of calf crop weaned	100	100	100
Av. birth weight per calf	68.1	73.4	66.3
Av. weaning weight per calf	349.5	382.7	346.0
Av. wt. per cow, weaning date	870.0	827.0	880.5
Av. gain or loss per cow during lactation	34.0	7.0	60.5
Av. pounds of beef, 1st year	349.5	344.5	346.0
1948			
Date winter period began	11/3/47	11/3/47	11/3/47
Av. wt. beginning winter period	837.5	826.0	857.0
Number of calves born	8	7	7
Percent of calf crop	80	70	70
Av. birth wt. per calf	66.6	67.1	54.3
Date winter period ended	4/21/48	4/21/48	4/21/48
Av. wt. end winter period	704.0	726.5	722.0
Av. gain or loss winter period	-143.5	-99.5	-135.0
Av. wt. per cow, 6/9/48	839.5	825.5	891.0
Av. gain, 6/9/48	19.0	5.5	71.0

TABLE XVI

Summary of data on weights of heifers at Stillwater

	Lot 1	Lot 2	Lot 3
Number per lot	10	10	10
Date project began	1/31/47	1/31/47	1/31/47
Av. initial weight	420.0	420.5	421.0
Date winter period ended	4/24/47	4/24/47	4/24/47
Av. weight end winter period	454.5	451.0	457.5
Av. gain or loss winter period	+34.5	+30.5	+36.5
Date summer period ended	11/3/47	11/3/47	11/3/47
Av. weight end summer period	734.0	721.0	709.5
Av. gain summer	279.5	270.0	252.0
Date winter period ended	4/21/47	4/21/48	4/21/48
Av. weight end winter period	684.5	694.0	729.0
Av. gain or loss winter period	-49.5	-27.0	+19.5
Date summer period began	4/21/48	4/21/48	4/21/48
Av. wt. 6-9-48	835.5	831.0	874.5
Av. gain to 6-9-48	415.5	410.5	453.5

they averaged 333.8 pounds. At the conclusion of the fattening period on April 28, 1948, the steers averaged 698.3 pounds. No differences among the steers from cows maintained on various levels of phosphorus intake were noted. The average daily gain of all steers for this period was 1.85 pounds per head. One steer became badly foundered shortly after being placed on feed. The summary statistics of the steers from each lot of cows at both stations in Table XVIII.

TABLE XVIII

Feed consumption data of steers at Wilburton and Stillwater

I.	Average feed consumption (lbs):		
	Whole oats		0.08
	Ground milo		11.84
	Cottonseed meal		1.52
	Prairie hay		4.16
	Salt		0.03
	Ground limestone		0.006
		Total	17.626
II.	Feed per cwt. gain (lbs):		
	Whole oats		4.00
	Ground milo		639.00
	Cottonseed meal		83.00
	Prairie hay		224.00
	Salt		1.00
	Ground limestone		0.30
		Total	951.30

TABLE XVIII

Summary date of steers at Wilburton and Stillwater
October 14, 1947 to April 28, 1948

	Number Per Lot	Average Initial Weight	Average Final Weight	Average Daily Gain	Average Selling Price
A. Wilburton:					
Lot 1	1	274	589	1.76	$173.76
Lot 2	2	282	574	1.64	169.18
Lot 3	4	278	555	1.56	165.98
B. Stillwater					
Lot 1	7	359	710	1.98	218.99
Lot 2	6	371	723	1.98	222.55
Lot 3	7	331	660	1.85	202.12

DISCUSSION

WILBURTON

The soils at the Wilburton experimental area were found to be very low in available phosphorus and the phosphorus content of the forage grown thereon was extremely low throughout most of the year. Of the grass samples analyzed, only one (April) was found to be above the 0.12 percent level considered by Watkins (1937) and Mitchell (1947) to be the minimum level which will provide for adequate phosphorus nutrition of grazing cattle. No appreciable differences were noted in the phosphorus content among the predominant grasses. The prairie hay fed during the winter period was lower in phosphorus than the average high quality prairie hay reported by Morrison (1940).

The daily intake of phosphorus for the cows and heifers of lot 1 during the first winter period was 0.93 and 1.10 grams per 100 pounds of body weight, respectively. The intake for the second winter season was 1.08 and 1.21 grams per 100 pounds of body weight in the lot 1 cows and heifers respectively. Under the conditions of this experiment the phosphorus intake was found to be inadequate to support optimum growth of heifers or meet the needs of cows during gestation and lactation. Average plasma phosphorus levels during the second winter period of the cows of lot 1 was 1.99 mg. percent. The average for the lot 1 heifers was 3.13 mg. percent. Inorganic phosphorus values as low as 1.0 mg. percent were noted in nursing cows exhibiting pronounced symptoms of aphosphorosis. These values are considerably below the borderline value reported by Black and co-workers (1942). During the second winter period, blood phosphorus values of individual cows as low as 2.0 mg. percent were observed without deficiency symptoms being manifested which agrees with the work of Knox, Benner and Watkins (1941). These workers reported that cows with blood plasma levels of from 2.0 to 3.0 mg. percent of phosphorus were observed during the winter months and that the animals were in excellent health. The dry cows of lot 1 were apparently able to meet their phosphorus requirements as evidenced by increased body weight and improved general appearance. Unthriftness, extreme emaciation, stiffness, low phosphorus blood values and other symptoms of aphosphorosis were observed in lactating cows which were similar to those reported by Theiler (1924) and Eckles and Palmer (1927).

The phosphorus requirements established by other workers for beef cattle are higher than the daily intake of the cows and heifers in lot 1. Armsby (1917) analyzed the data of Lawes and Guilbert and found that during the first year fattening steers and heifers retained 5,609 grams of calcium and 2,972 grams of phosphorus, or an average daily retention of 15.37 grams of calcium and 8.14 grams of phosphorus. Watkins (1937) reported unsatisfactory results with mature cattle when the daily phosphorus intake fell below 10 grams and the daily calcium intake fell below 20 grams.

The phosphorus intake of the lot 2 cows and heifers during the first winter period was 1.48 grams per 100 pounds of body weight. The intake during the second winter period was 1.60 and 1.61 grams per 100 pounds of body weight, for the cows and heifers respectively, which failed to support optimum growth of growing heifers or maximum performance of producing cows. When phosphorus supplementation was begun for the winter period so as to provide approximately 1.6 grams of feed phosphorus per 100 pounds of body weight the plasma phosphorus levels of the lot 2 cows increased from 2.10 mg. to above 5.0 mg. percent. The values for the lot 2 heifers increased from 3.5 mg. percent to more than 5.0 mg. percent during the same period. The increased dietary intake of phosphorus resulted in greater gains, higher blood phosphorus levels and an improvement in general body appearance.

The phosphorus intake of the lot 3 cows and heifers for the first winter season was 2.61 and 2.40 grams per 100 pounds of body weight, respectively.

The intake for the second winter period was approximately the same. This level was considered adequate for optimum growth and skeletal development of the heifers. Supplementation of dicalcium phosphate to increase the intake to 2.5 grams of feed phosphorus per 100 pounds of body weight during the second winter period resulted in increased weight, higher plasma phosphorus levels as well as an improvement in thrift and body appearance of the heifers. The general appearance and thrift of the cows of lot 3 was noticeably better than that of the other two lots but reproduction as measured by percentage calf crop was not optimum. This has suggested that these cows either received insufficient phosphorus during the preceeding grazing season to insure a normal percentage of conception or that some other factor contributed to this condition.

During the summer period, the phosphorus values in the lot 1 cows dropped from 4.9 mg. on April 24, 1947 to 2.5 mg. per 100 ml. plasma. The average plasma phosphorus values of the lot 1 heifers dropped from 5.4 mg. percent to 3.8 mg. for the same period. Cows nursing calves during this period lost weight rapidly and several became stiff and "creepy". No symptoms of a phosphorus deficiency were noted among the dry cows in this lot although low blood phosphorus values prevailed during the latter part of the period.

Clinical symptoms of aphosphorosis were noted in several of the cows of lot 2 during the summer period. At the beginning of this period the average plasma phosphorus level for all the cows of this lot was 6.2 mg. percent. The level decreased to 2.1 mg. at the close of the summer grazing season. For the same period the plasma phosphorus concentration in the lot 2 heifers decreased from 7.0 mg. percent to 3.5 mg. As the grass neared maturity it became necessary to add dicalcium phosphate to the ground rock salt mixture so as to provide an estimated intake of 1.5 grams per 100 pounds of body weight for the cows and heifers of lot 2. This estimated intake was inadequate to maintain a constant plasma phosphorus value in either the cows or heifers of this lot.

During the summer grazing season plasma phosphorus of the lot 3 cows declined from 6.6 mg. to 2.6 mg. per 100 ml. For the same period phosphorus level of the lot 3 heifers decreased from 8.6 mg. percent to 3.4 mg. percent. Apparently neither the cows nor the heifers consumed adequate amounts of the dicalcium phosphate -- ground rock salt mix to maintain plasma phosphorus levels. When the dicalcium phosphate was mixed with the corn gluten meal during the winter months to insure a daily phosphorus intake of approximately 2.5 grams per 100 pounds of body weight the blood phosphorus values increased to 7.4 mg. and 8.2 mg. percent for the cows and heifers, respectively.

Examination of the data reveal that the plasma calcium levels throughout this experiment remained within the normal range for cattle receiving adequate amounts of this element. This would be anticipated from the calcium content of the hay and grass fed.

The calcium -- phosphorus ratios during the winter periods ranged from 4.1 to 2.4 to 1 for three lots of heifers and from 4.5 to 2.5 to 1 for the three lots of cows. Bohstedt (1942) and other workers reported that the absolute amount of calcium and phosphorus in the dietary is of greater significance to the welfare of the animals than the ratio between the two elements. Lamb and co-workers (1934) reported that ratios as wide as 6.5 to 1 have been satisfactory for raising dairy calves. In this study adequate phosphorus was fed to the heifers.

The plasma carotene levels showed marked fluctuations throughout the course of this study. The lowest values were observed at the beginning of the experiment when the carotene intake was lowest. The carotene levels in all lots remained within the normal range. Payne and Kingman (1947) reported that cows with plasma levels as low as 82.88 $\pm$ 4.11 mcg. per 100 ml. of plasma showed no symptoms of a deficiency.

Such factors as age, gestation, lactation and dry weather did not appreciably affect the hemoglobin content of the blood. The average for all animals at this station was between 9.1 and 10.6 grams per 100 ml. of blood. Dukes (1947) reported an average of 12.03 grams per 100 ml. of blood as normal for cattle. Neal and Becker (1933) reported average values for beef cattle of 10.95 $\pm$ 1.54 to 11.06 $\pm$ 1.40 grams. Hemoglobin determinations were made because low hemoglobin levels have been reported in this area. These data indicate that the cattle were not deficient in some substance which might result in low hemoglobin levels. The data reported in this study indicate that there is no relationship between the hemoglobin content of the blood and the blood plasma phosphorus levels which is in agreement with the studies of Black and co-workers (1942).

No significant differences were noted in the red blood cell content among the supplemented and non-supplemented lots. Dukes reported 6,325,000 as the average number of red blood cells per cubic millimeter of blood. The indirect colorimetric method was standardized by direct microscopic counts.

The lot 2 and 3 cows were heavier than the cows of lot 1 on June 1, 1948. The lot 1 heifers gained 292.6 pounds as compared with gains of 368.5 and 413.0 pounds for lot 2 and 3, respectively.

STILLWATER

The soils at the Lake Carl Blackwell area were found to be borderline as regards available phosphorus and the forage grown thereon was found to be low in phosphorus during the dry seasons of the year. During the early part of the growing season, the phosphorus content of the pasturage was found to be about equal to the 0.12 percent level considered by Watkins (1937) and Mitchell (1947) to be the minimum level required for adequate phosphorus nutrition for grazing cattle. The prairie hay which was grown on soils of comparable phosphorus content were found to be lower in this element than the average for good quality western prairie hay reported by Morrison (1940).

The daily phosphorus intake for the cows and heifers of lot 1 during the first winter period was 0.89 and 0.70 grams per 100 pounds of body weight, respectively. The intake the second winter was approximately the same. Under the conditions of this experiment, the phosphorus intake was found to be inadequate to support optimum growth of heifers. The performance of the cows of lot 1 was about equal to that of the other two lots but they appeared less thrifty. The average plasma phosphorus levels during the second winter was 4.09 mg. percent for the heifers and 3.16 mg. for the cows. Only mild symptoms of a phosphorus deficiency were noted in nursing cows when the plasma phosphorus content fell below 2.0 mg. percent. Several cows in lot 1 with low blood phosphorus values were observed to be in excellent health which is in agreement with the findings of Knox, Benner and Watkins (1941).

The phosphorus requirements reported by Black and co-workers (1942) and Watkins (1937) for beef cattle are higher than the daily intake of the cows and heifers in lot 1. Most workers agree that when the average daily phosphorus intake falls below 10 grams for mature range beef cattle that unsatisfactory results will be obtained. During the second winter period, the cows in lot 1 lost 143.5 pounds and the lot 1 heifers lost 49.5 pounds.

The phosphorus intake of the lot 2 cows and heifers during the first winter was 1.67 and 1.43 grams per hundred pounds of body weight, respectively. At no time did the plasma phosphorus level in either group fall below the 4.0 mg. percent level reported by many workers as the borderline level consistent with good health. This level of intake was found to be adequate for growing heifers and bred cows. During the second winter the daily intake of the cow and heifers was 1.41 and 1.60 grams per 100 pounds body weight, respectively. Cows nursing calves showed low plasma phosphorus levels but were observed to be in excellent health. The average plasma phosphorus values for the lot 3 cows during this period was 5.29 mg. percent and was 5.44 mg. for the lot 2 heifers.

The phosphorus intake of the lot 3 cows during the first winter period was 2.68 grams per 100 pounds of body weight and 2.60 grams for the lot 3 heifers for the same period. The intake for the second winter was approximately the same. The average plasma phosphorus values for the second winter period were 6.01 mg. percent for the cows and 6.50 mg. for the heifers. The heifers showed an average gain of 19.5 pounds while the cows lost an average of 135.0 pounds which could be attributed to losses due to calving.

During the first summer grazing season, the plasma phosphorus values of the lot 1 cows decreased from 6.2 mg. percent to 3.3 mg. per 100 ml. For the same period, the blood phosphorus values in the lot 1 heifers declined from 6.6 mg. per 100 ml. of plasma to 5.2 mg. The lot 1 cows gained 182.5 pounds during the summer grazing period as compared with an average gain of 279.5 pounds for the lot 1 heifers. The lot 2 cows and heifers gained 169.0 and 270.0 pounds, respectively. The lot 3 cows and heifers for the same period gained 190.5 and 252.0 pounds, respectively. These findings are in agreement with those of Darlow and co-workers (1946). These workers reported that there was no benefit derived from supplying a mineral mixture to steers during the grazing season at the Lake Carl Blackwell area.

The blood calcium levels in all lots showed only slight fluctuations throughout the course of this study. All values were within accepted normal limits indicating that a lack of available calcium was no problem in this area. The calcium values ranged from 10.3 to 12.3 mg. per 100 ml. of plasma in the cows and 10.1 to 12.6 mg. percent in the heifers.

The calcium-phosphorus ratios in the cows varied from 4.6 to 1.9 to 1 in the three lots of cows and 4.4 to 2.3 to 1 in the heifer lots during the winter period.

Wide fluctuations in the average carotene level of all lots was noted. These levels were lowest during periods of low dietary carotene intake. Durint the second winter period, these levels were observed to be very low in each lot. From February 2, 1948 to March 18, 1948 the carotene values in the lot 1 cows ranged from 68.0 micrograms per 100 ml. plasma to 84.6 mg. For the same period, the carotene values in the lot heifers ranged from 50.6 to 63.5 mg. per 100 ml. plasma. These levels are for the most part below the 97.18 ± 7.68 micrograms for young range Hereford cows and 82.88 ± 4.11 micrograms for mature cows reported by Payne and Kingman (1947). To prevent the effects of a prolonged carotene deficiency in the three lots of cows, a crude carotene concentrate was fed the cows so as to supply a minimum of 92,000 I. U. per head daily. The feeding of carotene in addition to small amounts of green grass prevalent in the winter feeding area during the early spring accounted for the increase in plasma carotene levels at the close of the winter period.

No correlation between the phosphorus intake and the average hemoglobin content of the blood was observed during this study which is in agreement with the findings of Black and co-workers (1942). The averages tend to be lower than the normal values of 10.4 to 10.7 per 100 cc. of blood as reported by McMay (1931) and 10.34 to 11.6 grams reported by Brooks and Hughes (1932).

No consistent differences were noted in the red blood cell content of the cattle at this area. The values found in this study were somewhat lower than the average reported by Dukes (1947).

There was no consistent difference in the weight of the cows at the end of the first year of this experiment. The weaning weights of the calves from cows of lots 1 and 3 were about the same. The calves of lot 2 weighed approximately 33 pounds more than the calves of lot 1 and 36 pounds more than the calves in lot 3. The percentage calf crop was approximately the same for all lots. From this standpoint of weight the heifers in lot 1 and 2 weighed approximately the same and the lot 3 heifers weighed approximately 35 pounds more than the other 2 lots.

STEERS PRODUCED BY COWS AT STILLWATER AND WILBURTON

The twenty-seven head of steers produced by the cows during the first year were full fed a standard fattening ration for 197 days. No differences in the fattening ability of steers produced by cows maintained on various levels of phosphorus intake were noted. A wide variation existed in the age of the steers which would account in part for the differences in the rate of gain and the average selling price per head.

SUMMARY AND CONCLUSIONS

Wilburton

1. The soils in this area were found to be low in available phosphorus and the herbage grown thereon was low in phosphorus content. Adequate amounts of calcium were found in the herbage to support normal growth of young cattle and reproduction and lactation of cows.

2. The feeding of 2.5 grams of feed phosphorus per 100 pounds of live weight per heifer during the period covered by this study produced heifers that were 120.4 pounds heavier than those in the non-supplemented lot. Heifers receiving 1.5 grams of phosphorus per 100 pounds of live weight daily for the same period weighed 75.9 pounds more than those not receiving any mineral. Not only were those heifers which received the phosphorus-rich supplement much heavier but they were much healthier and more vigorous.

3. Lactating cows and growing heifers did not obtain adequate phosphorus from the growing forage or prairie hay produced in this area. These data show that to insure good growth of young beef heifers a daily phosphorus intake of 2.5 grams of that element per 100 pounds of body weight is indicated during the winter period. Additional phosphorus is required during the summer grazing season.

4. Several of the cows on the low plane of phosphorus nutrition that nursed calves during the summer period exhibited pronounced phosphorus deficiency symptoms of unthriftiness, emaciation, stiffness and low blood plasma phosphorus levels. No symptoms were noted in the high-phosphorus lot.

Stillwater

1. Cows that received no phosphorus supplement and nursed calves were found to have low blood phosphorus levels but they did not develop severe

symptoms of aphosphorosis.

2. The feeding of dicalcium phosphate to growing heifers in this area did not result in a significant increase in gain over those in the non-supplemented lot. This suggested that the herbage was sufficiently high in phosphorus to promote normal growth of young heifers during the short period covered by this study.

Steers Produced at Wilburton and Stillwater

1. There were no differences in the average daily gain and the average selling price of the steers produced by cows maintained on various levels of phosphorus intake.

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