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DISSERTATION

THE EFFECTS OF FEEDING STEERS DIFFERENT LEVELS OF PHOSPHORUS, COPPER, VITAMIN D, AND PHYTASE ON FEEDLOT PERFORMANCE, SLAUGHTER CHARACTERISTICS, AND APPARENT PHOSPHORUS DIGESTIBILITY

Submitted by

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Animal Science Department

In partial fulfillment of the requirements

For the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Summer 2001

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY LEIGH ANNE HURLEY ENTITLED THE EFFECTS OF FEEDING STEERS DIFFERENT LEVELS OF PHOSPHORUS, COPPER, VITAMIN D, AND PHYTASE N FEEDLOT PERFORMANCE, SLAUGHER CHARACTERISTICS, AND APPARENT PHOSPHORUS DIGESTIBILITY BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

Committee on Graduate Work

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ABSTRACT OF DISSERTATION

THE EFFECTS OF FEEDING STEERS DIFFERENT LEVELS OF PHOSPHORUS, COPPER, VITAMIN D, AND PHYTASE ON FEEDLOT PERFORMANCE, SLAUGHTER CHARACTERISTICS, AND APPARENT PHOSPHORUS DIGESTIBILITY.

Four experiments were conducted to study the effect of feeding different levels of phosphorus, copper, vitamin D and phytase on the feedlot performance, slaughter characteristics, and apparent mineral digestibility of finishing steers. In experiment 1, 284 steers were randomized by breed, blocked by weight, and assigned to one of four treatments: 1) 0.24% phosphorus (P) and 10 ppm copper (Cu), 2) 0.24% P and 56 ppm Cu, 3) 0.35% P and 10 ppm Cu, and 4) 0.35% P and 56 ppm Cu. Treatments were added to a whole corn based finishing diet. Steers were weighed every 28 d throughout the trial and feed intake was recorded daily. At the termination of the study, slaughter data was collected. There were no differences seen between treatments for feedlot performance. Dressing percents differed ($P<0.05$) between treatments (60.69%, 60.56%, 60.11%, and 59.74%, 0.35% P and 56 ppm Cu, 0.35% P and 10 ppm Cu, 0.24% P and 56 ppm Cu, and 0.24% P and 10 ppm Cu, respectively). The effects of feeding different levels of phosphorus and vitamin D were studied in experiment 2. Experimental modeling was the same as experiment 1, with the exception that 283 steers were used. Treatments were: 0.24% P and 0 IU vitamin D (vit D), 0.24% P and 552 IU vit D, 0.35% P and 0 IU vit D, and 0.35% P and 552 IU vit D. There were no differences in feedlot performance. Feed and feces were collected during this trial to determine fecal output and apparent digestibility of phosphorus, magnesium, and calcium. There were no differences

($P>0.05$) observed. Experiment 3 was a completely randomized design using 288 steers. Treatments were: 0.29% and 0 FTU phytase, 0.31% P and 200 FTU phytase, 0.32% P and 400 FTU phytase, and 0.35% P and 0 FTU phytase. There were no differences for overall feedlot performance or slaughter data. Fecal phosphorus output was lowest for the 0.29% P and 0 FTU phytase treatment. Steers supplemented with 400 FTU phytase exhibited greater ($P<0.05$) apparent mineral digestiblities than the 0.35%P and 0 FTU phytase (90.45% vs. 51.32%). The 0.29% P and 0 FTU phytase exhibited greater ($P<0.05$) apparent digestibilities than the 0.35%P and 0 FTU phytase. Experiment 4 was a 3 x 3 Latin square designed to evaluate fecal output and apparent digestibility of phosphorus. Treatments were: 0.28% P and 0 FTU phytase, 0.28% P and 250 FTU phytase and 0.28% P and 500 FTU phytase. There were no differences between treatments for fecal mineral output or apparent digestibility, however, apparent digestibility was greater ($P<0.05$) for the 0.28% P and 500 FTU phytase treatment.

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VITAE

Leigh Anne Hurley was born November 10, 1961 in Marlin, Texas. She was raised in Franklin, Texas and graduated from Franklin High School in 1980. She graduated from Texas A & M University with a B.S. in Biochemistry in 1986. She received her M.S. in Animal Science in 1988 from Texas A& M. From 1989 until 1992, she was a research assistant in the Nutrition Section of the Department of Animal Science at Texas A & M University. In 1993, she was employed as a HHMI research technician in the Molecular and Human Genetics Department at Baylor College of Medicine in the lab of Dr. Arthur Beaudet. In 1996, she began pursuing her doctoral degree in Animal Science at Colorado State University under the guidance of Dr. Tim Stanton. Presently, she is employed at Texas A& M University in the Department of Biochemistry in the lab of Dr. Dorothy Shippen, as a senior research associate.

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INTRODUCTION

In 1995, the Council for Agricultural Science and Technology reported that the U.S. agricultural industries generated over $900 billion in annual revenues. Animal agriculture accounted for approximately 50% of annual gross agricultural receipts (100). However, in 1995 (4) less than 2% of the U.S. population was directly involved with agriculture. More and more of agricultural lands have become urbanized which triggers tension between the agricultural industry and a public that may not be as sympathetic or patient towards agricultural endeavors. Livestock and poultry operations have become more centralized and concentrated. Because of improved genetics, nutrition, management, and technology; productivity has improved considerably (111). With animal agriculture becoming more concentrated and an urbanized public encroaching on it, the disposal of animal wastes and the potential of environmental pollution has become a major concern.

Prior to the advent of synthetic fertilizers, animal wastes (manures) were considered a valuable agricultural resource. Manure is still an excellent source of soil fertility and amendment, however the focus on land application of manure has moved from it being a source of soil improvement to a potential source of environmental pollution, particularly water pollution. Land application of manure not only adds biodegradable organic material and essential minerals for plant growth (specifically nitrogen and phosphorus) but also has been shown to reduce soil wind erosion (40). It is also the most common route of manure disposal, particularly from confined animal feeding operations (CAFO).

In many areas of the world, particularly in Europe where intensive animal production systems are located, manure is tightly regulated by governmental agencies. Although the United States has not instituted restrictions of the magnitude of those in force in Europe, there is legislation and regulation governing the location of confined animal feeding operations, the disposal of manure, and its application as a fertilizer. These laws originate at both the state and federal level and there is growing concern that there will be more restrictions instituted in the future. Most of the laws in place are concerned with water quality and the potential of pollution that can be generated by a CAFO. There are two types of potential pollution sources that can be generated by a CAFO, point source and nonpoint source. Point sources result from either direct discharges of manures or wastewaters from the CAFO itself or manure storage areas into surface waterways. Nonpoint sources include the potential for sediment, nutrient, and bacteria runoff to surface water that has leached from these areas or from areas that have had manure applied to them (5, 15, 28, 40, 44, 79, 90, 97). In addition, there have been regulations placed upon CAFO's regarding public nuisances such as odors, flies, and dust (48, 104).

In her 1996 review, Morse (79) pointed out that Federal regulations, which are overseen by the environmental protection agency (EPA), are the least stringent. Modifications, implementation, and enforcement of these regulations are left up to regional, state, and local entities that further refine the federal regulation so that they apply to that specific area and problem. Because the defining and enforcement of laws or mandates are left up to regional and local agencies, the specifics and implementation of them vary from region to region as do time schedules for implementation.

Legislation concerning water quality began prior to 1950 (87). This legislation has been modified and added to since, such as the Clean Water Act (CWA) of 1972 (88). The Clean Water Act of 1972 identifies livestock operations as point source contaminators if they have 1,000 head of beef cattle and no direct waterway or 300 head of beef cattle if a waterway is present (79, 88). This legislation requires that the affected livestock operations obtain permits to discharge through section 402 of the CWA (National Pollution Discharge Elimination System, NPDES). Morse (79) pointed out that discharges are identified as discharges to surface waters, or as discharges from the actual point source. Nonpoint sources of pollution were focused on by Public Law 100-4 (86). This law broadly defines nonpoint sources as pollution sources not addressed by previous legislation. In 1995, the U.S. General Accounting Office (GAO) reported that manure was the primary source of phosphorus pollution in the northeastern and southeastern states. Commercial fertilizer was cited as the source of phosphorus pollution in the central and western states (79, 103).

One of the best documented examples of the effect of environmental regulation was reported by Boggess et al. (9) and Clouser et al. (19) on the impact of the Dairy Rule of Florida (92). The Dairy Rule requires that cattle be fenced away from waterways, that structures are installed to minimize erosion, and runoff water from high intensity use areas, such as milking barns and feedlots, be collected and contained. Landowners are required to monitor total nitrogen, nitrate nitrogen, total phosphorus, and orthophosphorus, on a quarterly basis. Site specific management plans are required and must be approved by the Department of Environmental Resources. Noncompliance results in fines up to $10,000 per day (82). Boggess et al. (9) reported that compliance cost the producer $568 per cow or nearly $600,000 per dairy. Clouser et al. (19) investigated the consequence of the Dairy Rule on Okeechobee County, Florida as a whole. They reported that the Dairy Rule had the effect of a decrease in total sales revenue of $47.6 million, a loss of 465 full-time jobs, and a decrease in almost $9 million in earnings, countywide.

There are effects of environmental legislation that are not as obvious but will potentially have as crucial economical results as those in Okeechobee County, Florida. One such effect is that livestock producers may be considered as high-risk clients from lending agencies and insurers (82), especially until liability issues concerning manure use and misuse are ruled upon by the courts. The matter of environmental risk as a factor affecting agricultural loans is becoming policy by lending institutions (51).

A major obstacle to utilizing animal wastes efficiently is its water content. Animal waste routinely contains between 60 and 99% water (20, 65). Water contents as high as these present problems with transportation and storage. This makes application near generation sources much more practical than transport to distant locations. Manure application to fields increase the organic matter content of the soil, which in turn improves the soils structure, tilth and aids in decreasing soil compaction and crusting (25). When manure is applied to a no-till field, there can be increased residue on the surface that may reduce erosion (38). There is not a consensus as to whether animal wastes are superior to an equivalent amount of inorganic fertilizer in increasing crop yields (20, 65). However, when manure is applied in an excess of what nutrients are required by a specific crop, or at a time when crops do not utilize the nutrients as well, such as during dormancy when nutrients such as nitrogen and phosphorus are lost from the land and are regarded as pollution (25). This loss does not occur because of one or two imbalanced manure applications but is a result of a gradual accumulation of unused nutrients, which then cause the soil to become saturated. When manures are applied to land simply as a method to dispose of waste or with disregard to crop requirements, soil nutrient status, and manure nutrient profiles, excess nutrients will accumulate and soil saturation will occur.

Manures are commonly applied to meet a crop's nitrogen requirement. One example is corn. When manure is applied to meet the nitrogen requirements of corn, the amount of phosphorus applied will typically exceed the crop needs (4). However, nitrogen-based (N-based) manure application to phosphorus demanding crops such as alfalfa does not lead to phosphorus excesses. Eghball and Gilley (38) reported that in three studies conducted in Nebraska during 1996 and 1997 on the effect of N or P-based manure and compost runoff concentration of phosphorus and nitrogen components in no-till and disked systems. They reported that N-based manure or compost application to no-till soil caused a significant increase in runoff concentrations of dissolved phosphorus, bioavailable phosphorus, and ammonium as compared to tilled conditions. Repeated soil tests on manured soils are needed to monitor soil phosphorus levels so that soil phosphorus saturation is prevented.

A pound of phosphorus from manure or sludge, as a source of phosphorus for crops, is considered equivalent to a pound of phosphorus from an inorganic fertilizer (39). Under situations where soil phosphorus retention is high, phosphorus from manure is more available for plant utilization than phosphorus from inorganic sources (39). Beef feedlot, poultry, and swine manures have been found to contain inorganic phosphorus in amounts that range from 45 to 70 % of total phosphorus. In the first year of application, availability of phosphorus from cattle feedlot manure can be as high as 70% (39). A large percentage of phosphorus contained in manure itself is soluble (25). Comfort and Eghball (26) reported that as manure decomposed, phosphates are rapidly converted to iron and aluminum phosphates in acidic soils and calcium phosphates in alkaline soils. The availability of phosphorus from inorganic and organic sources is influenced not only by the soil's physical and chemical properties, but also the level of available phosphorus already in the soil (93). In his article, Mikkelsen (76) stated that in the soil, phosphorus is bound tightly to soil particles and is only slightly soluble under most agricultural conditions. This results in a very slow release of a very small amount of total soil phosphorus and therefore is a low leaching risk. However, different soils have different binding capacities. Clay soils possess a high binding capacity to these phosphates, but this capacity can be overwhelmed when phosphorus is applied in excess. Sandy soils do not possess this level of absorption, therefore inorganic phosphates are more likely to be leached from the soil if phosphorus is applied in excess of a crop's phosphorus requirement. Comfort and Eghball (26) pointed out that the organic materials in manure could inhibit calcium phosphates from binding to clay soils thus making them more available for leaching. Usually, when the absorption capacity of one layer of soil is reached, phosphorus leaches into deeper layers of the soil. However, if there is excessive application of phosphorus to the surface, then it can leach into waterways (93). Seventy-three percent of phosphorus that enters the soil is derived from fertilizers, both commercial and manure, and 23% from feedstuffs. However, only 35% leaves as animal or plant product. The 65% remaining is phosphorus excess and accumulates in the soil. Of this excess, 11% enters surface water as phosphorus pollution (21).

Phosphorus pollution problems occur when phosphorus bound to soil particles, soluble phosphorus, or manure phosphorus erode from a field into surface water (76) or when unbound inorganic phosphates are leached. When the soil-bound phosphate reaches surface water, phosphorus solubility increases and stimulates algae growth, aquatic vegetative growth, and surface vegetative mats. This increase in eutrophication decreases the oxygen content of lakes and waterways. (8, 32, 36, 37, 111). The decrease in oxygen can reach critical levels that are unable to support aquatic animal life. A common result is fish kills in slow moving waterways and lakes.

Of all livestock, ruminants produce the most manure (483,000 million kg, wet basis), followed by poultry and swine (41,000 and 36,000 million kg, wet basis, respectively) (21). Of this, 0.2%, 0.4%, and 1.2% is phosphate in ruminant, swine, and poultry manure, respectively. Manure composition usually mimics the composition of an animal's diet.

In his 1996 article, Williams (111) asserted that a key area that will likely influence the requirements for land application of manures includes dietary manipulation to improve digestibility and reduce phosphorus concentrations voided in manure. A nutritional approach to manure phosphorus management would be more practical to the producer than attempting to control the problem from direct manure management. In order to manipulate dietary phosphorus to increase its digestion and to decrease its loss as manure, it is important to understand phosphorus metabolism and the interactions it has with other minerals, hormones, and enzymes, and investigate their benefit in modifying phosphorus digestion and fecal excretion.

CHAPTER II

LITERATURE REVIEW

Phosphorus

Phosphorus is the sixth most plentiful element in the body (1) and accounts for approximately 1% of the body's total weight (7). Phosphorus is found in all cells of the body and the extracellular fluid. Eighty-five percent of the body's phosphorus is stored as bone hydroxyapitite, while 14% is stored in soft tissue such as skeletal muscle. In the bone, phosphorus exists in a ratio of 3:5 with calcium. Only 1% is present in extracellular fluid such as blood (1, 7, 72). Phosphorus in the body is present as a phosphate, not in elemental form. Of the phosphorus present in the blood, 70% is in an organic form (phospholipid) and is not accessible as a phosphorus reserve. Of the remaining 30%, 10% is bound to protein, 5% is complexed with calcium and magnesium, and the remainder exists in a form of orthophosphate (1). Orthophosphate is found freely circulating as HPO_4^{2-} (50%), PO_4^{3-} (40%), and $H_2PO_4^{2-}$ (10%) (72).

The most obvious function of phosphorus, as a component of the skeletal system, is structural support and protection for the body's organs (16). Phosphorus is involved in almost every cellular event in the body. As a phospholipid, phosphorus is a constituent of the myelin sheath encasing the nerves and functions in nerve impulse transmission. Many B vitamins require the phosphorylation of their coenzymes to become activated complexes (50). Phosphorus is an essential component of the genetic building blocks, DNA and RNA. Phosphorylation is needed to either activate or deactivate many enzymes including those in second messenger systems that regulate protein synthesis.

Phosphate has been described as the major energy currency of the body (7). Carbohydrate catabolism requires an initial phosphorylation of glucose and fructose to begin its release of potential energy (3). Phosphate is essential for the subsequent storage of the potential energy released from carbohydrate catabolism in the form of ATP and GTP. Phosphorus, as a component of red blood cell 2,3-DPG, is necessary for the release of oxygen from hemoglobin (7).

Phosphorus Homeostasis

Phosphorus homeostasis is maintained by the actions of the intestines, the kidneys, and the bone. The intestines are the major site of phosphorus absorption, the kidneys are the chief organs responsible for phosphorus excretion, and the bone serves as the major site of phosphorus storage. Plasma phosphorus reflects the net rate of phosphorus flux between the intestine, kidney, and bone (1). Physiologic conditions associated with life cycle changes such as growth, gestation, and lactation, are associated with increased phosphorus requirements and a corresponding increase in phosphorus absorption, retention, and in extreme cases, bone resorption (1). Young, rapidly growing cattle require more phosphorus than do older cattle (50). Geriatric humans exhibit a decrease in phosphorus absorption and an increased urinary excretion often resulting in a negative phosphorus balance (1). The 1996 NRC (82) has set the recommended daily requirement of phosphorus as 0.22% of the ration, on a dry matter basis.

Dietary phosphorus is largely made up of phospholipids, phosphorylated sugars, phosphorylated proteins and amino acids, nucleic acids, inorganic phosphate, and phytate (1). In addition to phosphorus supplied by the diet, two thirds of the phosphorus that is secreted back into the gastrointestinal tract as saliva and bile are reabsorbed by the animal. Because of the acidic conditions of the stomach and the proximal small intestine, most dietary sources of phosphorus are available for absorption (1). However, phytate phosphorus, in general, is not.

Animals and humans do not produce the enzyme, phytase, which is required to degrade phytate and liberate phosphate (1). Phytase is synthesized only by yeasts, protozoa, and bacteria. In order for phytate phosphorus to become accessible to an animal, either it must be liberated prior to intake or phytase must also be consumed. Ruminants are assumed able to digest phytate phosphorus because of the presence of rumen bacteria and their production of phytase (112). However, several studies have contradicted this belief (34, 42, 73).

In mature, nongestating, animals, phosphorus absorption is linearly related to available phosphorus intake (105). Phosphorus is absorbed via active and passive transport in the intestines. Although phosphorus is absorbed along the entirety of the small intestine, the jejunum is the most active site (105). Phosphate is also passively absorbed in the duodenum and the ileum (30). In ruminants, phosphorus is also absorbed in the abomasum (14). When phosphate concentrations in the lumen of the intestines are lower than that of the blood, then active transport becomes the main route of absorption (1). Active transport of phosphorus is via a sodium dependent pathway made up of two components. One component is saturable and concentration dependent (6). The other is nonsaturable and concentration dependent (1). This is evident by the fact that the intracellular levels of phosphorus are relatively high in the enterocytes lining the intestines and the cell is electronegative (phosphorus, as it exists as phosphate, is negatively charged) so an active transport mechanism is requisite for phosphorus to enter the cell. However, phosphorus leaves the cell by diffusion (12).

Active transport of phosphorus can be up-regulated by 1,25 $(OH)_2$ D (dihydroxycholecalciferol, vitamin D) and is linearly related to the sodium concentration of the intestines (30). Vitamin D deficient chick intestines absorb phosphorus less rapidly than intestines of chicks supplied vitamin D (83).

The mechanism by which vitamin D increases phosphorus absorption is independent of its function in calcium absorption. Evidence for this was presented in a study by Tanaka and DeLuca (101) using rats with everted duodenums. In this study, calcium transport was induced with vitamin D and serum calcium and phosphorus became elevated. After five days, calcium transport capability was still elevated, however serum phosphorus levels had returned to pre-dosage levels. They also found that with parathyroidectimized rats injected with vitamin D, serum phosphorus levels were increased, thus the effect was not due to bone resorption. They further studied the effect of vitamin D on serum phosphorus levels in nephrectomized rats and found that after vitamin D was administered, serum phosphorus increased ruling out any possible effect vitamin D might have on renal reabsorption of phosphorus. They concluded that the phosphatemic effect of vitamin D was not associated with the calcium transport system, or as an indirect effect on PTH or renal absorption. From the research of Tanaka and DeLuca (101), it can be concluded that the influence of vitamin D is at the intestinal level and does not involve bone resorption or renal reabsorption. These are effects that vitamin D does exert on calcium homeostasis. Brickman et al. (12) reported that vitamin D, when administered to rats, increases phosphorus absorption in all segments of the small intestine with the effect on the jejunum being the most responsive. They also pointed out that the duodenum was the most responsive site of vitamin D mediated calcium transport. In a study by Karsenty et al. (63), it was found that vitamin D also caused a rapid increase in phosphorus uptake in duodenal enterocytes, in vitro. However, Maunder et al. (74) reported than in sheep, unlike monogastrics, diet induced hypophosphatemia did not increase plasma vitamin D concentrations and had no effect in regulating the metabolism or production of vitamin D.

Phosphorus Excretion

Fecal losses of phosphorus are primarily composed of undigested feed phosphorus, unavailable phosphorus such as phytate, and insoluble phosphate salts. A minor component of fecal phosphorus is the unabsorbed bile and saliva phosphorus and endogenous phosphorus lost in sloughing intestinal cells (1).

The kidney is the main regulatory organ for phosphate homeostasis and excretion. In an adult animal, the kidney excretes phosphate in an amount equal to the net phosphate absorption thereby maintaining a zero balance (7). The kidney has the ability to conserve body phosphate by reducing urinary excretion to almost zero when phosphate is depleted (31). Lang et al. (66) and Leviere-Pegoner et al. (68) reported that the fractional urinary excretion of phosphate by the kidney varies between 0.1 and 20% depending on blood phosphate levels. Absorbed dietary phosphorus level is the main regulator of kidney phosphorus reabsorption. When phosphorus levels are low, essentially all of the glomerular filtered phosphorus is reabsorbed. However, as the phosphorus load increases in the filtrate (as a reflection of the increased absorbed dietary phosphate on plasma phosphate levels), the renal reabsorptive capacity is exceeded and phosphorus is excreted in the urine. This threshold level represents the maximum mass of phosphorus reabsorbed per unit of filtrate volume (TmP/GFR) (1). The absolute value of the threshold level represents the concentration of phosphorus in the reabsorbed fluid that is being returned to circulation (67).

Kidney excretion of phosphorus is also under the control of parathyroid hormone that regulates the reabsorptive capacity of the renal tubules (1). Primary regulation of parathyroid hormone is by a calcium feedback mechanism. When blood calcium levels are low, then parathyroid hormone is needed to decrease calcium excretion by the kidney, to increase bone resorption, and to up-regulate the synthesis of vitamin D for increased intestinal absorption. However, parathyroid hormone has the opposite affect on renal phosphorus absorption. Parathyroid hormone lowers the TmP/GFR, so less of the glomerular filtrate phosphorus is reabsorbed. Phosphorus also has a direct affect on parathyroid hormone by having the ability to increase parathyroid synthesis when phosphorus urinary excretion is high, which is an indication of elevated serum phosphorus concentration (1). Because the dietary level of phosphorus influences urinary phosphorus excretion via serum phosphorus, an excess of dietary phosphorus results in nutritional secondary hyperparathyroidism. Hyperparathyroidism is manifested as excessive bone resorption (16).

Maunder et al. (74) reported than in sheep, diet induced hypophosphatemia did not increase plasma vitamin D concentrations and had no effect in regulating the metabolism or production of vitamin D. These findings are supported by the fact that only elevated serum phosphorus levels induce parathyroid hormone to increase vitamin D synthesis (1). Low serum phosphorus has no effect.

Phosphorus and Its Relationship with Other Nutrients

Calcium has both a direct and indirect affect on phosphorus absorption. Calcium and phosphorus can form insoluble complexes that inhibit both active and passive phosphorus absorption. Indirectly, elevated serum calcium inhibits vitamin D mediated phosphorus absorption by its affect on parathyroid hormone. The synthesis of vitamin D is inversely related to the serum concentration of calcium, so when serum calcium concentrations are high, vitamin D mediated phosphorus absorption is reduced. Parathyroid hormone has the indirect effect on regulating phosphorus absorption by its regulatory role in vitamin D synthesis in the kidney (67).

Other minerals have been implicated in altering phosphorus metabolism. One of the most common interactions is between phosphorus and aluminum. This is mainly a human occurrence because of excess aluminum ingestion of aluminum containing antacids. Aluminum binds with phosphorus in the intestines creating insoluble precipitants. The same effect is seen with excessive magnesium intake. For many years, copper has been implicated in altering phosphorus absorption and or metabolism. In a study by Shirley et al. (96) it was inferred that diets high in copper may increase phosphorus retention. It is known that copper, as a cofactor of lysyl oxidase, influences bone formation and therefore affects bone phosphorus (2, 84, 89).

Phosphorus Excess and Deficiency

Bone phosphorus, in the form of hydroxyapetite is the major phosphorus reserve in the body. The main effect of excess phosphorus is its stimulation of parathyroid hormone and the subsequent disruption of calcium homeostasis and increased bone resorption. Excess phosphorus may also cause diarrhea and has also been implicated in urinary calculi, reduced serum calcium, and increased serum phosphorus (50). Serum calcium to phosphorus ratios greater than 1:2 may produce fibrous osteodystrophy (excessive bone resorption) in growing or adult animals because of phosphorus-induced hyperparathyroidism (16). Low extracellular calcium concentrations also trigger an increase in parathyroid hormone, increasing bone resorption and phosphorus excretion, thus creating a phosphorus deficiency.

In severe phosphorus deficiency, animals may have weak, fragile bones and stiff joints because of bone resorption (50). Rickets is the most common sign of severe phosphorus deficiency in growing animals because of increased bone resorption. Another manifestation of severe phosphorus deficiency is a depraved appetite (pica). Phosphorus deficiency has been associated with anestrus, low conception rates, and reduced milk production.

Less severe phosphorus deficiencies result in reduced growth rates and poor feed utilization. The initial and basic effect of phosphorus deficiency is a depression in feed intake. Little (69) reported that there was a significant linear response in the voluntary intake of phosphorus deficient cattle when the cattle on an otherwise balanced diet were supplemented with phosphorus. In a study using 24 yearling Nellore steers, Echevarria et al. (34) reported that dicalcium phosphate supplementation significantly increased daily live weight per animal compared to non-supplemented treatments.

Vitamin D

Vitamin D is synthesized by the body in sufficient quantities under normal conditions. However, when exposure to sunlight is inadequate, supplementation is required. The recommended daily allowance of vitamin D for humans is 200 IU for adults and 300 IU for infants. To insure adequate vitamin D intake, milk and infant formula is fortified with supplemental vitamin D to equal 400 IU per quart, in the United States (58). The NRC (82) has set the recommended daily requirement for beef cattle in feedlot at 275 IU/kg of dietary intake, dry matter basis. Vitamin D can be introduced to an animal as an injection or a dietary supplement. When vitamin D is ingested, it is incorporated into the chylomicron fraction. About 80% of ingested vitamin D is absorbed across the intestinal mucosa into the lymphatic system (58).

Classic studies established that vitamin D promotes intestinal calcium and phosphate absorption and mediates the mobilization of calcium from bone (54). Vitamin D is present in the body in many forms, however only two are of biological significance: 25 hydroxycholecalciferol and 1,25 dihydroxycholecalciferol. Of these, 1,25 dihydroxycholecalciferol is considered the most significant in biological activity.

Vitamin D Synthesis

The precursor of vitamin D is 7-dehydrocholesterol undergoes photolysis, via sunlight exposure, in the epidermis and the dermis to form cholecalciferol (58, 75). The molecule, 25 hydroxycholecalciferol, is the major circulating form of vitamin D. However, it is an inactive form of vitamin D. It is synthesized via hydroxylation in the liver. It then must be hydroxylated once again in the kidneys to become the active form of vitamin D (1,25 dihydroxycholecalciferol). 1,25 Dihydroxycholecalciferol is the most potent and fastest acting form of vitamin D (56). This metabolite is classified as a true sterol hormone (10). 1,25 dihydroxycholecalciferol selectively associates with a chromosomal receptor in intestinal mucosal cells (55) and functions to alter genetic expression (55) and therefore protein synthesis.

Vitamin D and Phosphorus

An early study by Wallis (106) reported that cows which were maintained on a vitamin D deficiency regimen exhibited lower plasma calcium and phosphorus concentrations (1/2 and 1/5 normal, respectively) bone breakage, decreased milk production, and many symptoms of rachitic calves. All of the cows failed to show estrus. Colvos et al. (23) stated that vitamin D deficiency seriously impaired calf growth, health, and feed efficiency. They reported that protein digestion, nitrogen retention, and ash digestion were diminished by low vitamin D intake, but dry matter digestion, ether extract, crude fiber, nitrogen free extract, and energy were not affected. The vitamin D deficient calves had increased basal metabolic rates and decreased blood calcium and phosphorus. Fountaine et al. (43) reported that vitamin D improved phytate phosphorus absorption by a mechanism that did not involve increasing the activity of intestinal phytase and phosphatases. These findings indicate that vitamin D possesses the ability to increase phytate phosphorus absorption that is independent of phytase and alkaline phosphatases.

Roles of Vitamin D

The effect of vitamin D is not limited to only its ability to increase intestinal absorption of calcium and phosphorus. Indirectly, vitamin D affects many physiological events either through its regulation of phosphorus and calcium or perhaps in another hormonal capacity. In an early study on the influence of nutrition on reproductive efficiency, Hignett and Hignett (57) observed that cattle in good vitamin D status (during the spring and summer) had increased fertility than cattle on lower vitamin D intakes (during the winter). In 1959, Hafez (49) stated that vitamin D indirectly affected female fertility by altering calcium and phosphorus utilization. This position was supported by Cohen (22) who conducted a study using 189 anestrus cows to compare vitamin D treated cows to those not treated with vitamin D and those treated with gonadotropin. More cows exhibited estrus in the vitamin D treated group compared to those that were not treated and to those treated with gonadotropin. Cohen (22) attributed the results to possible estrogenic activity of vitamin D. Ward et al. (107) reported that cows given 300,000 IU supplemental vitamin D weekly had earlier conceptions than non-supplemented cows. They suggested that vitamin D altered hormonal concentrations and or expression resulting in a higher incidence of observed estrus. The higher incidence of observed estrus resulted in shorter than average calving intervals due to detection. The uterus, ovary, placenta, breast, testes, embryonic liver, and embryonic muscle all possess receptors for vitamin D (58) however, vitamin D's effect on these tissues has not been reported.

Copper

The use of copper containing compounds to fight infection has been documented as early as 1550 B.C. (110). Ancient Egyptian writings described the topical use of verdrigis (copper acetate) and blue vitriol (copper sulfate) for eye inflammations and to promote proper wound healing. However, it was not until the early twentieth century that dietary copper deficiency was linked with a specific condition, anemia. Copper is required for over thirty different enzymes as a cofactor (53). Some of these enzymes are associated with iron metabolism, elastin formation, collagen formation, and melanin production (16). As a constituent of ceruloplasmin and ferroxidase II, copper oxidizes ferrous iron to ferric iron so that it can be transported (102). In its role in lysyl oxidase, it is essential for elastin and collagen cross-linking and therefore plays a role in bone formation. It is required for the active form of tyrosinase. Tyrosinase is required for melanin synthesis and thus pigmentation. Copper deficiency severely impairs immune function (29, 62, 113). Copper is also involved in other physiologic functions such as thermal regulation, cholesterol metabolism, glucose metabolism, and as a constituent of superoxide dismutase (SOD), which protects against oxidative damage caused by free radical production in the body (102).

Copper Homeostasis

Copper is a transition metal. In the body, it exists in two oxidation states, Cu^{+} and Cu^{2+} that may shift back and forth during enzyme action (102). Copper's beneficial impact on cells occurs in the micromolar range. It is also one of the more toxic elements (50) so its transport, storage, and metabolism are linked to systems that safeguard against its toxicity. Copper absorption is by a saturable active transport system at low dietary copper levels. The bioavailability of copper is influenced more by the amount of copper in the diet than the form of copper ingested. At higher dietary levels, absorption is by passive diffusion (102). As dietary copper concentrations increase, the fraction of copper absorbed decreases, however, the total amount of copper increases. Turnlund (102) stated that absorption declined from 56% at 0.8 mg/d to 12% at 7.5 mg/d but the amount absorbed doubled with a nine-fold increase in dietary copper. Absorbed copper is transported via the portal blood as a simple complex with albumin to the liver. In the liver, copper is bound to ceruloplasmin and accounts for 70 to 90% of all plasma copper (50). A specific interaction between ceruloplasmin and the cell membrane is required for cellular uptake of copper (50).

Copper's Interaction with Other Minerals

Nutrients known to interact with copper and affect its absorption in the small intestine are zinc and molybdenum. High dietary zinc induces intestinal metallothionein which has a high affinity for copper (102). It does this by up-regulating metallothionein synthesis. Metallothionein tightly binds copper in the enterocytes and essentially traps it in the cell. The copper metallothionein complex is then expelled when the cells slough off into the intestinal tract. The interaction of molybdenum with copper is of great concern in ruminants. Slight excesses of molybdenum in the presence of sulfide create insoluble complexes with copper, thiomolybdates (98, 102). These complexes create molybdenum toxicity and secondary copper deficiency.

Physiologic Effects of Copper

Allen et al. (2) stated that in premature infants with copper deficiencies, bone changes observed resemble those of scurvy. However, they reported that these changes improved rapidly after the administration of copper supplements. The effect of copper deficiency on the immune system is varied. Xin et al. (113) reported that SOD activities as a measure of antioxidation capability, in red blood cells, neutrophils, and whole blood decreased in copper deficient steers. These findings are in agreement with those of Xin et al. (113) that erythrocyte SOD activity in copper deficient sheep was one third of that of controls and with a previous study by Jones and Suttle (62) that noted the SOD activity in leukocytes and erythrocytes were significantly decreased in hypocupremic ewes. Hopkins and Failla (59) also reported that an intake of low, but not deficient, copper only minimally altered ceruloplasmin and liver SOD. They reported marginally low copper diets did significantly decrease mitogen-induced neutrophil killing ability in male rats. These findings indicated that ceruloplasmin and SOD activity were not sensitive indicators of copper status, especially in marginal versus adequate levels, but also that ceruloplasmin and SOD activity in marginal copper states were not correlated with changes in immunocompetence.

Several studies investigated the relationship between copper and inflammation. Suttle and Jones (99) reported an observation by Wyoming veterinarians linking low liver copper, abomasal ulceration, and pulmonary infections in calves raised on copper deficient range. It was postulated that the infections found in the gut and lung were more damaging because of uncontrolled inflammatory reactions. Ward et al. (108) investigated the effects of copper deficiency with or without high levels of molybdenum or iron. They reported that calves supplemented with copper exhibited the lowest response to intradermal injections of phytohemaglutinin (PHA).

Boyne and Arthur (11) studied the effects of copper deficiency on neutrophil function in cattle. They reported that copper deficiency did not affect the ability of the neutrophils to ingest Candida albicans, but neutrophils from copper deficient steers were less able to kill the ingested yeast than were the neutrophils from steers fed a diet supplemented with copper (64% decrease in killing ability). Cerone et al. (13) reported that the total number of leukocytes was not affected by copper deficiency, but the differential white cell counts were altered. It was also reported that polymorphonuclear neutrophils were found to be less metabolically active. These findings are in agreement with the findings of Jones and Suttle (62) who reported that in copper deficient sheep, the leukocyte killing capacity of Candida albicans was significantly reduced. Copper repletion restored the killing ability of the neutrophils. Xin et al. (113) also confirmed that phagocytic capacity was not affected by copper deficiency but killing capacity was reduced. Ward et al (109) studied the effect of copper level in growing steers on immune response and reported that copper supplementation corrected immune depression but supplementation to animals adequate in copper did not improve immunocompetence. These studies suggest that supplemental dietary copper above adequacy does not necessarily improve immune function.

Copper and Performance

In a study using 36 yearling Hereford heifers, Clawson et al. (18) reported that copper supplementation had no significant effect on heifer weights or feed consumption in the absence of molybdenum. They did however, find that copper sulfate tended to decrease gains over 120 d when compared to copper glycinate and to heifers receiving no copper supplementation (0.49 kg/d, 0.58 kg/d, and 0.54 kg/d, copper sulfate, copper glycinate, and control, respectively). Howard (60) reported that when copper was supplemented to unthrifty zebu and zebu cross cattle, that copper did produce a significant weight increase. They also reported that whole blood inorganic phosphorus concentrations were not affected by treatment. In a 1980 experiment, Maro and Kategile (71) reported that when calves were supplemented with copper, cobalt, or copper and cobalt. Calves that were supplemented with only copper had weight gains that were numerically lower than those supplemented with copper and cobalt.

The Relationship Between Copper and Phosphorus

The relationship between copper and phosphorus has not conclusively been established. In an early experiment, Comar et al. (24) using rats fed copper, molybdenum and copper, and molybdenum, dosing with radioactive phosphorus (^{32}P) resulted in a reduction in phosphorus accumulation in rats fed the combination supplement. When rats were fed phosphorus, molybdenum, and a combination of phosphorus and molybdenum, then dosed with radioactive copper, the rats supplemented with only phosphorus had a five-fold decrease in liver copper. In 1950, Shirley et al. (96) performed an experiment using four Jersey steers drenched with copper sulfate, sodium molybdate, a combination of the two minerals, and a control; then injected with radioactive phosphorus. They reported the steer receiving the copper sulfate exhibited a dramatic decrease in urine phosphorus when compared to the control steer (28 mg vs 2300 mg, respectively). These results inferred that diets high in copper may decrease urinary loss of phosphorus therefore copper supplementation may increase phosphorus retention.

Phytic Acid and Phytase Activity

Phytic acid, *myo*-inositol 1,2,3,4,5,6-hexakis acid, is the chief storage form of phosphorus in seeds and vegetative storage tissues (91). Phytic acid, or phytate as it is more frequently termed, accounts for 40-90% of a plant's phosphorus reserve (52). Phytate concentration rapidly increases in seeds during maturation (70, 91). The molecule itself has a phosphorus content of 28.2% (91). Phytate serves the cell not only as a phosphorus reserve, but also initiates dormancy and antioxidant protection in seeds (45, 47, 91). As an inositol, phytate is an energy source (27). Phytate is also a potent chelating agent (52, 85). This is a great advantage to plants because phytate binds and holds minerals for later use as the plant matures. Phytate chelates many macro and micro minerals that are nutritionally important such as calcium, cobalt, copper, iron, magnesium, manganese, selenium, and zinc (52). However, affinities for these minerals vary with pH, competition between the minerals, and the molar concentration ratios of these minerals to phytate (85).

Plant Phytate

The concentration of phytate phosphorus in feedstuffs depends largely on the part of the plant from which they are derived (91). Different feedstuffs vary in their phytate content. In 1918, Rather (90) reported that the amount of phytate phosphorus varied from 66% of the total phosphorus in wheat shorts to 89% in rice polishings (91). Common feedstuffs such as corn, oats, sorghum, wheat, triticale, have reported phytate phosphorus values, as a percentage of total phosphorus, of 68%, 61%, 71%, 65%, and 67%, respectively (37, 80, 91). Oilseed meals such as soybean meal, cottonseed meal, and sunflower meal have phytate phosphorus values of 60%, 70%, and 50%, respectively (91, 95) as a percentage of total phosphorus. However, alfalfa meal, and corn distillers grain only contains only 12%, and 22% phytate phosphorus as a percentage of total phosphorus (80, 91).

Phytase

Phytase is classified as a phosphatase and is able to catalyze the hydrolysis of a phosphate ester. Phytase specifically cleaves the phosphate bonds of phytate. However, general phosphatases, such as alkaline phosphatase, are also able to cleave phytate but only function in alkaline environments (64). The environment of the stomach and the small intestine are acidic, not basic. The phytase used commercially is produced from *Aspergillus* niger. This phosphatase is a 3-phytase that initiates dephosphorylation of phytate at the 3-position (64). A major advantage of this enzyme is that it has optimum activity at two different pH: 2.5 and 5.5, therefore it is active in the stomach and the proximal intestine.

Dietary Phytate and the Effect of Supplemental Phytase

As stated previously, animals cannot synthesize phytase; only eukaryotes possess this ability. When phytate is fed to an animal, there is only a very limited amount of phytate that can be hydrolyzed and made available for absorption. Addition of a microbial phytase to an animal's diet alleviates this situation. Microbial phytase has been used commercially in swine and poultry nutrition since 1991 (64). It not only improves phytate phosphorus availability to the animal but also the availability of the compounds and minerals bound to phytate. The net effect is an increase in mineral availability and animal performance (64). It also has the indirect affect of decreasing the need for supplementation of phosphorus.

The use of phytase in the swine and poultry industry is widely accepted and used. However, it is not used in the beef industry because of the assumption that the rumen bacteria produce sufficient phytase to hydrolyze phytate and no supplemental phytate is required. If these assumptions are true, then all plant material phosphorus would be available to cattle and the relative biological value of phytate would theoretically be near 100. The relative biological value of phosphorus to ruminants has been reported to be 100 for calcium phosphate, 107 for monosodium phosphate, 100 for dicalcium phosphate and 92 for steamed bone meal (77). However, the relative biological value of calcium phytate and phytate phosphorus is only 60 (77). Other researchers have reported that the phytate in feedstuffs are not as biologically available to ruminants as they have been presumed to be. Mathur (73) reported that only 65% of phytate phosphorus was digested when calcium chalk was fed to dairy cows. In 1961, Ellis and Tillman (41) found that only 25.5% of wheat bran total phosphorus was digested by sheep. They stated that this study indicated that phytate phosphorus was not digested in the rumen. A study by Dutton and Fontenot (33) supported the concept that ruminants were not able to completely digest phytate phosphorus. In this study, wether lambs were fed a purified diet and supplemented with either monosodium phosphate or a phytic acid solution. Results indicated that there were no significant differences in phosphorus absorption and absorption ranged from 59% for the phytic acid supplement to 63% for the inorganic supplement. It must be noted that the phytic acid was not naturally occurring in the diet, but supplied as a 70% solution of pure phytic acid and water.

In contrast, a study by Clark et al. (19) using 30 Holstein cows fed diets of 50% grain mixture and 50% corn silage reported that 98% of dietary phytate phosphorus was hydrolyzed to inorganic phosphorus. However, they also reported that prior to ensiling, corn silage contained 0.13% phytate phosphorus but after ensiling, it contained only 0.0012% phytate phosphorus, supposedly due to microbial phytase produced during fermentation process, indicating that the phosphorus supplied by the corn silage was liberated before consumption. They did not report if the complete diet was mixed prior to feeding. This conclusion is also supported by the findings of Morse et al. (78). In one of two experiments, Morse et al. (78) reported that in vitro fermentation with rumen fluid hydrolyzed greater than 95% in wheat middlings, rice bran, hominy, soybean meal, and dried distillers grains. In an in vivo experiment using 11 Holsteins, they reported that the digestion of phosphorus in phytate was greater than 99%, based on actual differences between intake and excretion. In an in vitro study to determine the phytase activity of ruminal bacteria, Yanke et al. (112) found that in 334 strains of 22 species of obligate anaerobic ruminal bacteria, phytase activity was present but varied greatly. They also reported that 96% of *Selenomonas* ruminatium tested positive for phytase. However, phytase activity was exclusively associated with the bacterial cells, not the ruminal fluid, indicating that phytate that was not ingested by the bacteria was not hydrolyzed.

CHAPTER III

MATERIALS AND METHODS

Experiment 1: Phosphorus and Copper Trial

Two hundred eighty-four steer calves (mean initial weight = 288 kg) were used to evaluate the effects of phosphorus and copper concentration on growth performance and carcass characteristics. The study was conducted at the Eastern Colorado Research Center, located 18 mi. from Akron, CO. The study began on November 20, 1996 and ended on May 2, 1997. At the initiation of the trial, steers were processed, vaccinated with Cattlemaster® 4 and a 7-way clostridial and implanted with Synovex® Plus at the initiation of the trial and 60 d into the trial. The experimental design used was a 2 x 2 factorial arrangement with approximately 71 steers per treatment.

Steers were stratified by breed, blocked by weight, and randomly assigned to one of four treatment groups. Each group consisted of six pens of 11 or 12 steers each. Breed was estimated by hair color or pattern and each steer was assigned to one of four breed groups. Breeds were predominantly British or British crossbreed. Each steer within a breed group was assigned a number between one and four. Steers with the same numbers were grouped together. Treatment was then randomly assigned to each number group. Steers within each treatment group were then blocked by weight. Steers were assigned to either a heavy weight pen or a light weight pen according to whether their weight fell above or below the average of all steer weights within that treatment. Each treatment group had an equal number of heavy and light weight pens.

The four treatments were: 1) 0.24% phosphorus and 10 ppm copper, 2) 0.24% phosphorus and 56 ppm copper, 3) 0.35% phosphorus and 10 ppm copper, and 4) 0.35% phosphorus and 56 ppm copper. The basal diet was analyzed to contain 0.24% phosphorus and 9.5 ppm copper (Olsen's Agricultural Laboratory, Inc., McCook, NE). Additional phosphorus and copper was introduced to the diet via supplementation to supply 0.35% phosphorus, 10 ppm and 56 ppm copper. Diets were started at 70% concentrate (whole corn and supplement) and increased to a final 93.2% concentrate finishing diet over a four-week period. Final diet composition is presented in table 1. Treatment supplements are presented in table 2.

Steers were weighed, after feeding with no water restriction, on two consecutive days at the beginning and end of the study. Steers were weighed at 28-day intervals throughout the trial period. Feed intake per pen was recorded daily. At the termination of the study, steers were shipped to Excel (Fort Morgan, CO) for processing. Hot carcass weight, yield grade, and quality grade data were assessed at the time of slaughter.

TABLE 1. Finishing diet composition fed to feedlot steers supplemented with different levels of phosphorus and copper.

Ingredients	100% DM basis
Whole corn	87.5
Alfalfa hay	3.4
Wheat straw	3.4
Supplement[a]	5.7

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[a] See table 2 for composition.

Performance and slaughter data were analyzed by the General Linear Models procedure of SAS® (94). Pens were used as the experimental units for all analyses. Least Square Means were used to correct for missing observations and treatment effects.

Experiment 2: Phosphorus and Vitamin D Trial

Two hundred eighty-three steer calves (mean initial weight = 290 kg) were used to evaluate the effects of feeding different levels of phosphorus and vitamin D on growth performance, carcass characteristics, feed and fecal minerals, and apparent digestibility of phosphorus, calcium, magnesium, copper, and zinc. The study was conducted at the Eastern Colorado Research Center, located 18 mi. from Akron, CO. The study began on December 2, 1997 and ended on May 18, 1998. At the initiation of the trial, steers were vaccinated with Cattlemaster® 4 and a 7-way clostridial and implanted with Revelor S® at the initiation of the trial and 60 days into the trial. The experimental design used was a 2 x 2 factorial arrangement with approximately 71 steers per treatment.

TABLE 2. Pelleted supplement fed to feedlot steers supplemented with different levels of phosphorus (P) and copper (Cu).

	Treatment			
Nutrient Specifications, % DM	0.24% P and 10 ppm Cu[a]	0.24%P and 56 ppm Cu[a]	0.35% P and 10 ppm Cu[a]	0.35% P and 56 ppm Cu[a]
Crude Protein, %	65	65	65	65
Phosphorus, %	0	0	3.4	3.4
Calcium, %	9	9	9	9
Magnesium, %	1	1	1	1
Potassium, %	3.4	3.4	3.4	3.4
Salt, %	4.25	4.25	4.25	4.25
Sulfur, %	0.6	0.6	0.6	0.6
Cobalt, ppm	1.8	1.8	1.8	1.8
Selenium, ppm	3	3	3	3
Manganese, ppm	400	400	400	400
Zinc, ppm	220	220	220	220
Copper, ppm	100	950	100	950

Additives for all supplements:

Monensin, mg/kg	574.6
Tylosin, mg/kg	198.9
Vitamin A, IU/kg	110,500
Niacin, g/kg	2.21
Vitamin E, IU/kg	884

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[a] Total ration phosphorus and copper level, DM basis.

Steers were stratified by breed, blocked by weight, and randomly assigned to one of four treatment groups. Each group consisted of six pens of 11 or 12 steers each. Breed was estimated by hair color or pattern and each steer was assigned to one of four breed groups. Breeds were predominantly British or British crossbreed. Each steer within a breed group was randomly assigned a number between one and four. Steers with the same numbers were grouped together. Treatment was then randomly assigned to each number group. Steers within each treatment group were then blocked by weight. Steers were assigned to either a heavy weight pen or a light weight pen according to whether their weight fell above or below the average of all steer weights within that treatment. Each treatment group had an equal number of heavy and light weight pens.

The four treatments were: 1) 0.24% phosphorus and 0 IU/kg vitamin D, 2) 0.24% phosphorus and 552 IU/kg vitamin D, 3) 0.35% phosphorus and 0 IU/kg vitamin D, and 4) 0.35% phosphorus and 552 IU/kg vitamin D. The basal corn diet was analyzed to contain 0.24% phosphorus (Olsen's Agricultural Laboratory, Inc., McCook, NE). Additional phosphorus was introduced to the diet via supplementation to supply 0.35% phosphorus. The NRC (82) does not require supplementation of vitamin D in feedlot diets when cattle receive adequate sunlight exposure. However, the NRC (82) has set the recommended daily requirement for beef cattle at 275 IU/kg of DMI. Vitamin D was supplemented at twice the recommended daily requirement. Diets were started at 65% concentrate (whole corn) and increased to a final 89.86% whole corn finishing diet over a four-week period. Final diet composition is presented in table 3. Treatment supplements are presented in table 4.

Steers were weighed, after feeding with no water restriction, on two consecutive days at the beginning and at the end of the study. Steers were weighed at 28-day intervals throughout the trial period. Feed intake per pen was recorded daily.

Two pens from each treatment were used to access the apparent digestibility of phosphorus, calcium, magnesium, copper, and zinc. The pens used in this phase of the study were randomly chosen. Chromic oxide was used as a digestion marker. Chromic oxide was pelleted with wheat middlings as a binder and fed to these pens at a level of 0.2% of the diet for a period of 17 days. On day 15, 16, and 17, feed and feces were collected from each pen. Feed was sampled from several different locations in each pen's bunk soon after feed delivery each morning during the sampling period. Samples of feces were collected from six different fresh droppings within the pens each morning of the sampling period. All samples were immediately frozen after collection. Each individual pen's daily samples were dried in a force-draft oven at 65° C for 24 h and a composite

TABLE 3. Finishing diet composition fed to feedlot steers supplemented with different levels of phosphorus and vitamin D.

Ingredients	100 % DM basis
Whole corn	83.16
Alfalfa hay	7.10
Corn Stalks	3.04
Supplment[a]	6.70

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[a] See table 4 for composition.

TABLE 4. Pelleted supplement fed to feedlot steers supplemented with different levels of phosphorus (P) and vitamin D (vit D).

	Treatment			
Nutrient Specifications, % DM	0.24% P and 0 IU vit D[a]	0.24%P and 552 IU vit D[a]	0.35% P and 0 IU vit D[a]	0.35% P and 552 IU vit D[a]
Crude Protein, %	65	65	65	65
Phosphorus, %	0	0	2.28	2.28
Calcium, %	9	9	9	9
Magnesium, %	1	1	1	1
Potassium, %	3.4	3.4	3.4	3.4
Salt, %	4.25	4.25	4.25	4.25
Sulfur, %	0.6	0.6	0.6	0.6
Cobalt, ppm	1.8	1.8	1.8	1.8
Selenium, ppm	3	3	3	3
Manganese, ppm	400	400	400	400
Zinc, ppm	220	220	220	220
Copper, ppm	100	100	100	100
Vitamin D, IU/kg	0	552	0	552
Additives for all supplements:				
Monensin, mg/kg		574.6		
Tylosin, mg/kg		198.9		
Vitamin A, IU/kg		110,500		
Niacin, g/kg		2.21		
Vitamin E, IU/kg		884		

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[a]Total ration phosphorus and vitamin D (IU/kg), DM basis.

was made by equal weight. Samples were then ground and analyzed for phosphorus, calcium, magnesium, zinc, copper, and chromium by an independent laboratory (Olsen's Agricultural Laboratory, Inc., McCook, NE).

At the termination of the study, steers were shipped to Excel (Fort Morgan, CO) for processing. Hot carcass weight, yield grade, and quality grade data were assessed at the time of slaughter. Performance, slaughter data, feed, feces, and apparent digestibilities were analyzed by the General Linear Models procedure of SAS® (94). Pens were used as the experimental units for all analyses. Least Square Means were used to correct for missing observations and treatment effects.

Experiment 3: Phosphorus and Microbial Phytase Trial

Two hundred eighty-eight steer calves (mean initial weight = 278 kg) were used to evaluate the effects of feeding different levels of phosphorus and microbial phytase expressed as phytase units (FTU) on growth performance, carcass characteristics, fecal mineral content, and the apparent digestibility of phosphorus, calcium, magnesium, copper, and zinc. The study was conducted at the Eastern Colorado Research Center, located 18 mi. from Akron, CO. The study began on November 17, 1998 and ended on May 17, 1999. At the initiation of the trial, steers were vaccinated with Cattlemaster® 4 and a 7 way clostridial and implanted with Synovex® Plus at the initiation of the trial and 60 d into the trial. The experimental design used was a complete randomized design with approximately 72 steers per treatment.

Steers were randomized by breed, blocked by weight, and assigned to one of four treatment groups. Each group consisted of six pens of 11 or 12 steers each. Breed was estimated by hair color or pattern and each steer was assigned to one of four breed groups. Breeds were predominantly British or British crossbreed. Each steer within a breed group was randomly assigned a number between one and four. Steers with the same numbers were grouped together. Treatment was then randomly assigned to each number group. Steers within each treatment group were then blocked by weight. Steers were assigned to either a heavy weight pen or a light weight pen according to whether their weight fell above or below the average of all steer weights within that treatment. Each treatment group had an equal number of heavy and light weight pens.

The four treatments were: 1) 0.29% phosphorus and 0 FTU phytase, 2) 0.31% phosphorus and 200 FTU phytase 3) 0.32% phosphorus and 400 FTU phytase, and 4) 0.35% phosphorus and 0 FTU phytase. The diets were analyzed individually to contain 0.29%, 0.29%, 0.32%, and 0.31% phosphorus for the 0.35% phosphorus and 0 FTU phytase, 0.29% phosphorus and 0 FTU phytase, 0.32% phosphorus and 400 FTU phytase, and 0.31% phosphorus and 200 FTU phytase treatments, respectively (Olsen's Agricultural Laboratory, Inc., McCook, NE). An additional 0.05% phosphorus was introduced to the 0.35% phosphorus and 0 FTU phytase treatment diet via supplementation with dicalcium phosphate. No supplemental phosphorus was added to any other treatment. Cattle were started on diets of 65% whole corn and increased to a final 94% concentrate finishing diet over a four-week period. Final diet composition is presented in table 5. Treatment supplements are presented in table 6.

Two pens from each treatment were used to access the apparent digestibility of phosphorus, calcium, magnesium, copper, and zinc. The pens used in this phase of the study were randomly chosen. Chromic oxide was used as a digestion marker. Chromic oxide was pelleted, with wheat middlings as a binder, and fed to these pens at a level of 0.2% of the diet for a period of 17 days. On day 15, 16, and 17, feed and feces were collected from each pen. Feed was sampled from several different locations in each pen's bunk soon after feed delivery each morning during the sampling period. Samples of feces were collected from six different fresh droppings within the pens each morning of the sampling period. All samples were immediately frozen after collection. Each individual pen's daily samples were dried in a force-draft oven at 65° C for 24 h and a composite was

TABLE 5. Finishing diet composition fed to feedlot steers supplemented with different levels of phosphorus and phytase.

	100% DM basis			
Ingredient	029% P and 0 FTU phytase[a]	0.31%P and 200 FTU phytase[a]	0.32% P and 400 FTU phytase[a]	0.35% P and 0 FTU phytase[a]
Whole corn	87	87	87	84
Millet hay	6	6	6	6
Supplement[b]	7	7	7	7
Dicalcium phosphate	0	0	0	4
Phytase				
200 FTU/kg	0	3	0	0
400FTU/kg	0	0	3	0

[a] Total ration phosphorus and phytase units (FTU), DM basis.
[b] See table 6 for composition.

TABLE 6. Pelleted supplement fed to feedlot steers supplemented with different levels of phosphorus (P) and phytase.

	Treatment			
Nutrient Specifications, % DM	0.29% P and 0 FTU phytase[a]	0.31%P and 200 FTU phytase[a]	0.32% P and 400 FTU phytase[a]	0.35% P and 0 FTU phytase[a]
Crude Protein, %	65	65	65	65
Phosphorus, %	0	0	0	0
Calcium, %	9	9	9	9
Magnesium, %	1	1	1	1
Potassium, %	3.4	3.4	3.4	3.4
Salt, %	4.25	4.25	4.25	4.25
Sulfur, %	0.6	0.6	0.6	0.6
Cobalt, ppm	1.8	1.8	1.8	1.8
Selenium, ppm	3	3	3	3
Manganese, ppm	400	400	400	400
Zinc, ppm	220	220	220	220
Copper, ppm	100	100	100	100

<u>Additives for all supplements:</u>

Monensin, mg/kg	574.6
Tylosin, mg/kg	198.9
Vitamin A, IU/kg	110,500
Niacin, g/kg	2.21
Vitamin A, IU/kg	884

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[a] Total ration phosphorus and phytase units (FTU), DM basis.

made by equal weight. Samples were then ground and analyzed for phosphorus, calcium, magnesium, zinc, copper, and chromium by an independent laboratory (Olsen's Agricultural Laboratory, Inc., McCook, NE).

Steers were weighed, after feeding with no water restriction, on two consecutive days at the beginning and at the end of the study. Steers were weighed at 28-day intervals throughout the trial period. Feed intake per pen was recorded daily. At the termination of the study, steers were shipped to Excel (Fort Morgan, CO) for processing. Hot carcass weight, yield grade, and quality grade data were assessed at the time of slaughter.

Performance, slaughter data, feed, feces, and apparent digestibilities were analyzed by the General Linear Models procedure of SAS® (94). Pens were used as the experimental units for all analyses. Least Square Means were used to correct for missing observations and treatment effects.

Experiment 4. Phosphorus and Microbial Phytase Apparent Digestibility Trial

Six British/exotic mixed breed steers (average weight = 458 kg) were used in a replicated 3 x 3 Latin square design digestion trial to evaluate the effect of feeding different levels microbial phytase on fecal mineral content, and the apparent digestibility of phosphorus. Steers were maintained in three pens of two steers each. Pens were supplied with fresh wood-chip bedding as needed and cleaned daily. Two alternate steers were maintained in a separate pen from treatments steers but in the same housing unit. Alternate steers were fed the same basal diet as were the treatment steers. All steers had previously been halter broke and acclimated to metabolism stalls. All steers were stepped up from a 45% concentrate diet to a 92% concentrate diet over a six-week period from April

18, 1997 to May 28, 1997. Steers were fed 10% over maintenance level during this period, once daily to ensure complete intake of daily ration. Water was supplied, ad libitum.

Steers were blocked by weight into either a heavy or light weight group when compared to the average weight of all six steers. One heavy weight and one light weight steer were assigned to each experimental pen. Pen mates remained paired together and received the same diet and treatment throughout the experimental rotations. At the initiation of the experiment, treatments were randomly assigned to each pen. Treatment diet composition is given in tables 7 and 8. Treatments were rotated so that each pair of steers received each treatment for a consecutive 20 d period.

Chromic oxide was added to the daily ration as a digestion marker. Chromic oxide and phytase were added to the rations at the time of feeding. Both chromic oxide and phytase were added to 250 ml of distilled water to make a slurry. The slurry was then added to the diets as a top dressing and thoroughly mixed with the ration. Chromic oxide was included in the diet at 0.2% of the diet DM. Phytase was added at 0 FTU, 250 FTU or 500 FTU per kg of diet DM.

Rotation periods consisted of a 15 d treatment acclimation period and a five day collection period. During the acclimation period treatments were fed to steers in their specific pens. The treatment diets were fed at maintenance level to ensure complete consumption of the ration. On the morning of d 15, steers were placed in individual metabolism crates and individually fed their respective treatment rations at maintenance level. Water was supplied, ad libitum, via individual watering devices. Steers were maintained in metabolism crates for a period of six days. During this six d period, each ration was mixed individually and sub-sampled prior to feeding. Approximately 250 g of each diet was collected. Total feces collection was attempted for each steer each day. Urine contaminated feces was not collected; however a sample of fresh uncontaminated feces from that time period was collected. Five percent of each day's fecal output (wet basis) was sampled. All samples were immediately frozen after collection. All samples were dried in a force-draft oven at 65° C for 24 h. At the end of each rotation, a 5 d composite sample was obtained for each steer. Samples were then ground and sent for analysis of phosphorus, calcium, magnesium, zinc, copper, and chromium by an independent laboratory (Olsen's Agricultural Laboratory, Inc., McCook, NE).

TABLE 7. Diet composition fed to digestion trial steers supplemented with different levels of phosphorus and phytase.

	100% DM basis		
Item	0.28 % P and 0 FTU phytase[a]	0.28 %P and 250 FTU phytase[a]	0.28% P and 500 FTU phytase[a]
Whole corn	86.99	86.99	86.99
Alfalfa hay	8.01	8.01	8.01
Supplement[b]	5	5	5
Phytase[c]			
5000 FTU/g	0	5	10

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[a] Total ration phosphorus and phytase units (FTU), DM basis.
[b] See table 8 for composition.

TABLE 8. Pelleted supplement fed to digestion trial steers supplemented with different levels of phosphorus and microbial phytase.

	Treatment		
Nutrient Specifications, % DM	0.28 % P and 0 FTU phytase[a]	0.28 %P and 250 FTU phytase[a]	0.28% P and 500 FTU phytase[a]
Crude Protein, %	65	65	65
Phosphorus, %	0	0	0
Calcium, %	9	9	9
Magnesium, %	1	1	1
Potassium, %	3.4	3.4	3.4
Salt, %	4.25	4.25	4.25
Sulfur, %	0.6	0.6	0.6
Cobalt, ppm	1.8	1.8	1.8
Selenium, ppm	3	3	3
Manganese, ppm	400	400	400
Zinc, ppm	220	220	220
Copper, ppm	560	560	560

<u>Additives for all supplements:</u>

Monensin, mg/kg	574.6
Tylosin, mg/kg	198.9
Vitamin A, IU/kg	110,500
Niacin, g/kg	2.21
Vitamin A, IU/kg	884

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[a] Total ration phosphorus and phytase units (FTU), DM basis.

Feed, feces, and apparent digestibilities were analyzed by the General Linear Models procedure of SAS® (94). Steers were used as the experimental units for all analyses. Least Square Means were used to correct for missing observations and treatment effects.

CHAPTER IV

RESULTS AND DISCUSSION

Experiment 1. Phosphorus and Copper Trial

The results presented in table 9 indicate that there were no significant differences in overall DMI or ADG between steers supplemented with any of the four combinations of phosphorus and copper. However, when analyzed by period, there were significant differences ($P<0.05$) detected between treatments for both DMI and ADG. During the second period (29 to 56 d), DMI was significantly greater ($P<0.05$) for steers fed the 0.35% P and 56 ppm Cu than for steers fed the 0.35% P and 10 ppm Cu and 0.24% P and 10 ppm Cu (9.17 kg/d, 8.35 kg/d, and 6.21 kg/d, respectively). There were no differences between DMI for the 0.35% P and 56 ppm Cu treatment and the 0.24% P and 56 ppm Cu treatment (9.17 kg/d and 9.81 kg/d, respectively) during this period. The differences between ADG seen during the first period (1 to 28 d) may be due to both the level of phosphorus and copper supplemented, however, the differences seen during the third period (57 to 84 d) are attributable to copper supplementation alone. From the data presented in table 9 there was no consistent advantage in supplementing phosphorus on increasing

DMI or ADG, however, supplementing copper above the 1996 NRC requirement may yield a slight, however not significant, increase in both DMI and ADG. There were no differences exhibited between treatments in feed efficiency (table 10). During the second period (29 to 56 d) steers receiving the 0.24% P and 10 ppm Cu treatment had significantly superior feed efficiency than steers receiving the other three treatments. This result could be interpreted as an indication that feeding copper at a level above the requirement level (82) had an effect of depressing feed efficiency since both treatments containing 56 ppm of copper had the highest feed to gain ratios. However, this pattern was not repeated again throughout the trial. There was no consistent advantage of feeding one treatment, when compared to the others, in improving feed efficiency.

Slaughter data was collected on 189 steers (table 11). Data on 95 steers was not collected due to technician error. From the data collected, there were no differences seen between treatments except for dressing percent. The dressing percent from steers fed the 0.35% P and 56 ppm Cu treatment were significantly greater ($P<0.05$) than the steers fed the 0.24% P and 10 ppm Cu treatment (60.69 and 59.74 dressing percent, respectively). There were no differences seen between the other treatments. Steers receiving 10 ppm Cu exhibited a greater percentage of carcasses grading choice than did those steers receiving 56 ppm Cu (98% and 98% vs. 87% and 92%, 0.35% P and 10 ppm Cu and 0.24% P and 10 ppm Cu vs. 0.35% P and 56 ppm Cu and 0.24% P and 56 ppm Cu, respectively).

There are no previously reported interactions between phosphorus and copper on feedlot performance. The research of Comar et al. (24) suggests that phosphorus supplementation reduced copper retention in rats. They reported that when rats were supplemented with phosphorus then dosed with radioactive copper, liver copper levels were

TABLE 9. Least square means for feedlot performance of finishing steers supplemented with different levels of phosphorus (P) and copper (Cu).

	Treatment				
Item	0.24% P and 10 ppm Cu[a]	0.24% P and 56 ppm Cu[a]	0.35%P and 10 ppm Cu[a]	0.35% P and 56 ppm Cu[a]	SEM
No. Pens	6	6	6	6	
No. Steers	71	71	72	70	
Initial wt, kg/head	290	281	288	294	5
Final wt, kg/head	561	550	545	557	15
DMI, kg/d per head					
1 to 28 d	7.51	7.82	7.65	7.74	0.30
29 to 56 d	8.21[b]	8.81[cd]	8.35[c]	9.17[d]	0.28
57 to 84 d	9.53	9.57	9.68	9.78	0.28
85 to 114 d	10.11	9.86	9.86	10.26	0.35
115 to 142 d	10.37	10.14	10.16	10.28	0.37
143 to 170 d	10.81	10.77	10.52	10.94	0.41
1 to 170 d	9.09	9.50	9.37	9.69	0.30
ADG, kg/d per head					
1 to 28 d	1.57[bc]	1.52[b]	1.55[bc]	1.68[c]	0.05
29 to 56 d	1.77	1.83	1.82	1.76	0.08
57 to 84 d	1.25[b]	1.43[bc]	1.30[bc]	1.49[c]	0.07
85 to 114 d	2.20	2.33	2.18	2.19	0.11
115 to 142 d	1.78	1.71	1.64	1.69	0.09
143 to 170 d	1.60	1.70	1.74	1.74	0.07
1 to 170 d	1.69	1.75	1.70	1.76	0.02

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[a] Total ration phosphorus and copper level, DM basis.
[b,c,d] Means in a row with different superscripts differ ($P<0.05$).

TABLE 10. Least square means for feed efficiency (feed to gain) of finishing steers supplemented with different levels of phosphorus (P) and copper (Cu).

	Treatment				
Item	0.24% P and 10 ppm Cu[a]	0.24% P and 56 ppm Cu[a]	0.35%P and 10 ppm Cu[a]	0.35% P and 56 ppm Cu[a]	SEM
Feed to Gain Ratio					
1 to 28 d	4.82	4.65	4.97	5.11	0.23
29 to 56 d	3.52[b]	5.04[c]	4.63[c]	5.05[c]	0.23
57 to 84 d	7.73	6.53	7.62	6.92	0.47
85 to 114 d	4.65	4.54	4.55	4.56	0.31
115 to 142 d	6.83	6.25	6.22	6.13	0.34
143 to 170 d	6.83	6.25	6.10	6.45	0.38
1 to 170 d	5.57	5.52	5.68	5.70	0.20

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[a] Total ration phosphorus and copper level, DM basis.

[b,c] Means in a row with different superscripts differ ($P<0.05$).

decreased when compared to rats not supplemented with phosphorus. However, when rats were supplemented with copper then dosed with radioactive phosphorus there was no effect on phosphorus accumulation as was seen when rats were supplemented with both copper and molybdenum. From this research it has been suggested that phosphorus supplementation has an effect of decreasing copper retention in animals. Numerous studies (11, 99, 108, 113) have shown that copper deficient sheep and cattle have depressed immune function. However, there is no improvement in immunity by supplementing copper

TABLE 11. Least square means for slaughter data of finishing steers supplemented with different levels of phosphorus (P) and copper (Cu).

Item	0.24% P and 10 ppm Cu[a]	0.24% P and 56 ppm Cu[a]	0.35%P and 10 ppm Cu[a]	0.35% P and 56 ppm Cu[a]	SEM
	Treatment				
No. Pens	6	6	6	6	
No. Steers[b]	47	48	46	48	
Hot Carcass wt, kg	325	333	330	335	8
Dressing %	59.74[d]	60.11[de]	60.56[de]	60.69[e]	0.30
Yield Grade	3.01	2.82	2.86	2.99	0.15
Marbling Score[c]	243	247	245	254	1.14
% Grading Choice	98	92	98	87	

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[a] Total ration phosphorus and copper level, DM basis.
[b] Data from 95 steers lost in packing plant.
[c] Marbling scores: 100's = trace, 200's = slight, 300's = small.
[d,e] Means in a row with different superscripts differ ($P<0.05$).

above adequate dietary levels (59). If increased dietary phosphorus decreases copper reserves, then animals would be more susceptible to disease. Impaired immunity would increase the number of unthrifty cattle in the feedlot due to either chronic or acute disease states. These cattle would exhibit decreased DMI, ADG, and an increased feed to gain ratio. From the data produced by this study, there was no indication that supplementing with phosphorus at 0.35% DMI had a deleterious effect on copper status to the extent that would be indicated by a consistent pattern of decreased performance. From the data presented above, there was no evidence for a phosphorus and copper interaction which causes a significant effect on feedlot performance.

Experiment 2. Phosphorus and Vitamin D Trial

The results presented in tables 12 and 13 indicate that there was no significant difference in overall DMI, ADG, or feed efficiency between steers supplemented with any of the four combinations of phosphorus and vitamin D. However, when analyzed by period, there were significant differences detected between treatments for both DMI and ADG (table 12). The differences between treatments during the first period for DMI were significant. The 0.35% P and 552 vit D treatment differed ($P<0.05$) from the 0.24% P and 0 IU vit D by 0.58 kg/d (8.06 kg/d vs. 8.64 kg/d, respectively). The 0.35% P and 552 vit D treatment had the lowest DMI than any other treatment (8.06 vs. 8.17, 8.30, 8.64 kg/d, 0.35% P and 552 IU vit D, 0.24% P and 552 IU vit D, 0.35% P and 0 IU vit D, and 0.24% P and 0 IU vit D, respectively). From this data, it could be inferred that the inclusion of vitamin D had a depressing effect on DMI. In contrast, during the third period (57 to 84 D) the 0.35% P and 552 IU vit D treatment resulted in the greatest DMI of all treatments, however it was only significantly different from the 0.35% P and 0 IU vit D treatment (9.42 vs. 8.55 kg/d, respectively).

TABLE 12. Least square means for feedlot performance of finishing steers supplemented with different levels of phosphorus (P) and vitamin D (vit D).

	Treatment				
Item	0.24% P and 0 IU vit D[a]	0.24% P and 552 IU vit D[a]	0.35%P and 0 IU vit D[a]	0.35% P and 552 IU vit D[a]	SEM
No. Pens	6	6	6	6	
No. Steers	70	72	70	71	
Initial wt, kg/head	288	291	291	290	9
Final wt, kg/head	569	577	575	581	11
DMI, kg/d per head					
1 to 28 d	8.64[b]	8.17[c]	8.30[bc]	8.06[c]	0.16
29 to 56 d	8.47	8.33	8.21	8.49	0.22
57 to 84 d	8.84[bc]	8.93[bc]	8.55[b]	9.42[c]	0.25
85 to 132 d	9.26	9.27	9.03	9.59	0.34
133 to 166 d	9.96	10.55	10.18	10.45	0.84
167 to 187 d	10.88	11.48	11.61	11.51	0.39
1 to 187 d	9.31	9.45	9.31	9.59	0.37
ADG, kg/d per head					
1 to 28 d	1.82	1.68	1.70	1.71	0.07
29 to 56 d	1.42[b]	1.71[c]	1.75[c]	1.78[c]	0.08
57 to 84 d	1.90	1.85	1.80	1.91	0.08
85 to 132 d	1.58	1.67	1.64	1.58	0.07
133 to 166 d	1.89	1.88	1.88	1.97	0.08
167 to 187 d	1.42	1.35	1.27	1.39	0.10
1 to 187 d	1.67	1.69	1.67	1.72	0.03

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[a] Total ration phosphorus and vitamin D(IU/kg), DM basis.

[b,c] Means in a row with different superscripts differ ($P<0.05$).

TABLE 13. Least square means for feed efficiency (feed to gain ratio) of finishing steers supplemented with different levels of phosphorus (P) and vitamin D (vit D).

	Treatment				
Item	0.24% P and 0 IU vit D[a]	0.24% P and 552 IU vit D[a]	0.35%P and 0 IU vit D[a]	0.35% P and 552 IU vit D[a]	SEM
Feed to Gain Ratio					
1 to 28 d	4.95	5.16	5.17	5.28	0.26
29 to 56 d	6.36[b]	5.29[c]	5.09[c]	5.09[c]	0.36
57 to 84 d	6.32	5.13	5.05	5.18	0.31
85 to 132 d	6.32	5.18	5.87	6.45	0.40
133 to 166 d	5.52	5.80	5.71	5.63	0.54
167 to 187 d	8.81	9.51	11.02	10.44	1.03
1 to 187 d	6.16	6.12	6.32	6.35	0.20

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[a] Total ration phosphorus and vitamin D(IU/kg), DM basis.

[b,c] Means in a row with different superscripts differ ($P<0.05$).

The trend of vitamin D supplementation improving DMI was observed throughout the remainder of the trial, although it was not significant.

During the second period (29 to 56 d) there was a significant difference between the ADG of the 0.24% P and 0 IU vit D treatment and all other treatments (table 12). There were no other significant differences in ADG between treatments for all other periods. The differences in mean ADG values for treatments did not follow a consistent pattern throughout the trial period. However, overall the ADG values for both of the vitamin D supplemented treatments were greater than the ADG values of the treatments not supplemented with vitamin D. These results were not significant.

Feed efficiencies (table 13) were different ($P>0.05$) only for the second period reflecting the differences between treatments in ADG (table 12). These values were only different ($P<0.05$) from the value of the 0.24% P and 0 vit D treatment. The pattern seen in both the DMI and ADG data is not evident in the feed to gain ratio data. The only significant differences between treatments were seen in the second period with 0.35% P treatments producing the best feed conversion ratios of all treatments. Overall, the 0.24% P treatments had the best feed conversion ratios, however these ratios were not significantly different from those of the 0.35% P treatments or from each other. From all performance data presented in tables 12 and 13, no significant benefit can be seen for supplementing phosphorus or vitamin D or both in combination to finishing cattle.

There were no differences ($P>0.05$) found between treatments for slaughter data (table 14). Steers receiving the 0.24% P and 0 IU vit D had the lowest hot carcass weight mean of all treatments ($P>0.05$). These cattle also had the lowest final weights ($P>0.05$, table 12).

The 0.24% P and 0 IU vit D treatment also exhibited the lowest ($P>0.05$) dressing percent of all treatments. The 0.35% P and 552 IU vit D treatment had a mean dressing percent that was approximately one percentage point greater than the means of the other treatments (61.31% vs. 60.52%, 60.35%, and 60.12%; 0.35% P and 552 IU vit D,

TABLE 14. Least square means for slaughter data of finishing steers supplemented with different levels of phosphorus (P) and vitamin D (vit D).

	Treatment				
Item	0.24% P and 0 IU vit D[a]	0.24% P and 552 IU vit D[a]	0.35%P and 0 IU vit D[a]	0.35% P and 552 IU vit D[a]	SEM
No. Pens	6	6	6	6	
No. Steers	70	72	70	71	
Hot Carcass wt, kg	344	352	351	355	6
Dressing %	60.12	60.35	60.52	61.31	0.87
Yield Grade	2.31	2.19	2.32	2.26	0.21
Quality Grade[b]	3.01	2.81	2.90	2.89	0.21
% Grading Choice	11	11	13	13	

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[a] Total ration phosphorus and vitamin D (IU/kg), DM basis.

[b] 1 = standard, 2 = select, 3 = choice

0.24% P and 552 IU vit D, and 0.24% P and 0 IU vit D, respectively). These values were not significantly different. The low percentage of cattle grading choice is most likely explained by the aggressive implant program utilized in this study.

Table 15 presents the means of feed and fecal mineral content. There were no differences ($P>0.05$) between treatments in feed mineral content, with the exception of phosphorus. Fecal mineral contents did not differ, with the exception of magnesium, between treatments. Fecal phosphorus levels were lower for steers not supplemented with phosphorus when compared to phosphorus supplemented steers. There were no differences between treatments in apparent digestibility. However, the 0.24% P treatments exhibited higher ($P>0.05$) values for all minerals. This effect is not due to the addition of vitamin D, since both the 0.24% P and 552 IU vit D and the 0.24% P and 0 IU vit D treatments were approximately equivalent in apparent digestibility of phosphorus, calcium, and magnesium. Fecal calcium was lower, although not significantly, for vitamin D supplemented steers. This is not an effect of an increase in calcium retention since calcium homeostasis and excretion is regulated via the kidney but perhaps a minor affect of increased absorption initiated by supplemental vitamin D.

The apparent digestibilities of phosphorus, calcium, and magnesium are given in table 15. There were no significant differences in apparent digestibility between treatments for any mineral analyzed. There is an obvious trend however, for the apparent digestibilities of phosphorus, calcium, and magnesium to be greater ($P>0.05$) in steers not supplemented with phosphorus with or without vitamin D supplementation. An explanation for a phosphorus effect for this occurrence cannot be conclusively explained by the literature available. Phosphorus deficiencies do increase endogenous vitamin D synthesis, thus increasing phosphorus and calcium absorption from the intestines. An increase in absorption would positively affect apparent digestibility of phosphorus and calcium. However, the dietary phosphorus level supplied to all steers in this study are above the 1996 NRC (82) which would prevent any deficiency syndrome. It would be logical to assume that

TABLE 15. Least square means for feed, fecal, and apparent digestibility of phosphorus (P), calcium (Ca), and magnesium (Mg) of finishing steers supplemented with different levels of phosphorus (P) and vitamin D (vit D).

	Treatment				
Item	0.24% P and 0 IU vit D[a]	0.24% P and 552 IU vit D[a]	0.35%P and 0 IU vit D[a]	0.35% P and 552 IU vit D[a]	SEM
Feed Mineral Content[b]					
% P	0.24[c]	0.24[c]	0.35[d]	0.35[d]	0.06
% Ca	0.57	0.57	0.57	0.57	0
% Mg	0.24	0.24	0.24	0.24	0
Fecal Mineral Content[b]					
% P	0.60	0.61	0.70	0.86	0.39
% Ca	2.15	1.90	1.95	1.76	0.39
% Mg	0.53[c]	0.46[cd]	0.40[d]	0.38[d]	0.37
Apparent Digestibility					
% P	88.30	87.21	81.28	72.90	5.15
% Ca	82.37	83.31	68.21	66.00	8.19
% Mg	90.18	90.69	84.32	82.70	2.22

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[a] Total ration phosphorus and vitamin D (IU/kg), DM basis.
[b] Mineral content on DM basis.
[c,d] Means in a row with different superscripts differ ($P<0.05$).

any increase in phosphorus and calcium absorption induced by phosphorus level, would be affected by the addition of vitamin D to the diet. However, there is no pattern observable to this affect. There is no known affect of phosphorus level on magnesium absorption. The major site of magnesium absorption is prior to the small intestine via an active transport system not regulated by vitamin D (1). It has been proposed that vitamin D improves phytate phosphorus absorption (43). Phytate phosphorus is the major phosphorus form in whole corn so it therefore constitutes the major source of phosphorus in the diets fed. Phytate is known to chelate many minerals, such as calcium and magnesium rendering them unavailable for absorption. It can be assumed that if vitamin D improves phytate phosphorus absorption then it would also indirectly improve the absorption of minerals chelated to the phytate molecule (52). However, the addition of supplemental vitamin D in this trial did not indicate this result. Vitamin D supplemented treatments did not improve apparent digestibility of any of the minerals analyzed. Magnesium absorption increases as magnesium intake increases (46). Total magnesium intake would be greater for steers having greater DMI. Phosphorus level had no effect on DMI (table 12), therefore magnesium absorption and apparent digestibility can be assumed to be unaffected by DMI intake and total magnesium intake amounts.

Experiment 3. Phosphorus and Microbial Phytase Trial

Table 16 presents feedlot DMI and ADG means for finishing steers fed treatments consisting of different levels of phosphorus and microbial phytase. There were no significant differences between treatments for the DMI and ADG means when broken down into periods or as overall values. There were no distinguishable patterns exhibited by treatments throughout the trial. The results from table 16 were echoed in the feed to gain ratios presented in table 17. There were no significant differences or patterns found between treatments for feed efficiencies either by period or by overall feed to gain ratios.

Slaughter data for steers receiving different levels of phosphorus and phytase are presented in table 18. There were no differences ($P>0.05$) between treatments for hot carcass weight, dressing percent, yield grade, or quality grade. In this experiment, when compared the two previous experiments, the treatment group receiving the greatest amount of phosphorus did not exhibit the highest dressing percent mean. Dressing percent means were greatest for steers receiving the 0.31 % P and 200 FTU phytase treatment, followed by steers receiving the 0.35% P and 0 FTU phytase, the 0.29% P and 0 FTU phytase, and the 0.32% P and 400 FTU phytase treatments (60.61%, 60.10%, 59.96%, and 59.07%, respectively).

Table 19 presents feed mineral, fecal mineral, and apparent digestibility data collected from finishing steers receiving different levels of phosphorus and phytase. Copper and zinc were also analyzed in this trial due to the ability of phytate to chelate these minerals (52). All treatments were significantly different in feed phosphorus content (0.35%, 0.29%, 0.32%, and 0.31%; 0.35% P and 0 FTU phytase, 0.29% P and 0 FTU phytase, 0.32% P and 400 FTU phytase, and 0.31% P and 200 FTU phytase, respectively). There were no significant differences between treatments for feed calcium, magnesium, copper, or zinc.

Fecal phosphorus output was greatest ($P<0.05$) for steers receiving the 0.35% P and 0 FTU supplement. However, the 0.29% P and 0 FTU treatment steers excreted less phosphorus than did steers receiving the 0.32% P and 400 FTU phytase treatment

TABLE 16. Least square means for feedlot performance of finishing steers supplemented with different levels of phosphorus (P) and phytase.

Item	0.29%P and 0 FTU phytase[a]	0.31% P and 200 FTU phytase[a]	0.32% P and 400 FTU phytase[a]	0.35% P and 0 FTU phytase[a]	SEM
	Treatment				
No. Pens	6	6	6	6	
No. Steers	73	73	71	71	
Initial wt, kg/head	280	279	277	278	13
Final wt, kg/head	538	524	533	535	15
DMI, kg/d per head					
1 to 28 d	7.14	7.49	7.81	7.61	0.46
29 to 56 d	8.89	8.69	9.19	8.74	0.39
57 to 84 d	8.59	8.03	8.62	8.62	0.32
85 to 119 d	9.80	9.14	9.54	9.25	0.31
120 to 155 d	10.33	10.11	9.99	10.16	0.33
156 to 190 d	10.93	10.51	10.52	10.65	0.24
1 to 190 d	8.91	8.62	8.89	8.80	0.27
ADG, kg/d per head					
1 to 28 d	1.72	1.67	1.66	1.72	0.12
29 to 56 d	1.65	1.72	1.55	1.67	0.11
57 to 84 d	1.85	1.74	1.94	1.78	0.10
85 to 119 d	1.53	1.44	1.50	1.41	0.08
120 to 155 d	2.10	2.02	2.13	2.25	0.08
156 to 190 d	1.00	1.26	1.07	1.23	0.15
1 to 190 d	1.64	1.65	1.64	1.65	0.04

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[a] Total ration phosphorus and phytase units (FTU), DM basis.

TABLE 17. Least square means for feed efficiency (feed to gain ratio) of finishing steers supplemented with different levels of phosphorus (P) and phytase.

	Treatment				
Item	0.29%P and 0 FTU phytase[a]	0.31% P and 200 FTU phytase[a]	0.32% P and 400 FTU phytase[a]	0.35% P and 0 FTU phytase[a]	SEM
Feed to Gain Ratio					
1 to 28 d	4.29	4.53	4.80	4.92	0.28
29 to 56 d	5.44	5.06	6.88	5.23	0.81
57 to 84 d	4.71	4.66	4.54	4.86	0.28
85 to 119 d	6.50	6.42	6.47	6.69	0.42
120 to 155 d	4.92	5.05	4.72	4.57	0.22
156 to 190 d	11.13	9.57	9.89	9.03	0.94
1 to 190 d	5.43	5.24	5.42	5.29	0.15

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[a] Total ration phosphorus and phytase units (FTU), DM basis.

and steers receiving the 0.31% P and 200 FTU phytase treatment (0.55%, 0.60%, and 0.66%, respectively). Since the phosphorus content of the treatments were not the same, the effect of increasing fecal phosphorus cannot be attributed to phytase supplementation.

There were significant differences between phosphorus, calcium, and magnesium apparent digestibility means of steers fed the 0.32% P and 400 FTU phytase treatment and steers fed the 0.35% P and 0 FTU phytase treatment (90.45 vs. 51.32%, 79.96% vs. 56.43%, and 89.63% vs. 44.09%; phosphorus, calcium, and magnesium, respectively). Although not significant (P>0.05) for any mineral analyzed, steers fed the 0.32% P and 400 FTU phytase exhibited greater apparent digestibility values than did steers fed the

0.29% P and 0 FTU phytase treatment. The apparent digestibilities of all minerals followed a definite pattern. Steers receiving the 0.32% P and 400 FTU phytase treatment had the greatest apparent digestibilities for phosphorus, calcium, magnesium, copper, and zinc, followed by steers receiving the 0.29% P and 0 FTU phytase treatment. The steers receiving the 0.35% P and 0 FTU phytase treatment exhibited the lowest apparent digestibilities for all minerals analyzed. The only treatment that was supplemented with phosphorus was the 0.35% P and 0 FTU treatment. All other treatment phosphorus levels were the result of naturally occurring phosphorus only.

Since whole corn was the major constituent of the diets, the majority of diet phosphorus was in the form of phytate phosphorus. It has been assumed by researchers (17, 78) that ruminants by virtue of rumen bacteria, possess enough phytase activity to adequately hydrolyze phytate and thus make available the phytate phosphorus and associated minerals and compounds for digestion by the ruminant. Clark et al. (17) reported that 98% of dietary phytate phosphorus was hydrolyzed to inorganic phosphorus when fed to dairy cattle and concluded that ruminants were adequate in phytase activity. Other researchers (33, 41, 73) have reported that phytate phosphorus was only partially hydrolyzed by ruminants. Mathur (73) reported that only up to 65% of phytate phosphorus was digested by dairy cows. In a study using whether lambs fed a 70% solution of pure phytic acid as a phosphorus supplement Dutton and Fontenot (33) reported only 59% of phytic acid phosphorus was absorbed while the absorption of a monosodium phosphate supplement was 63%.

TABLE 18. Least square means for slaughter data of finishing steers supplemented with different levels of phosphorus (P) and phytase.

	Treatment				
Item	0.29%P and 0 FTU phytase[a]	0.31% P and 200 FTU phytase[a]	0.32% P and 400 FTU phytase[a]	0.35% P and 0 FTU phytase[a]	SEM
No. Pens	6	6	6	6	
No. Steers	73	73	71	71	
Hot Carcass wt, kg	342	336	334	345	8
Dressing %	59.96	60.61	59.07	60.10	0.80
Yield Grade	1.93	1.91	1.91	1.91	0.11
Quality Grade[b]	2.43	2.65	2.58	2.52	0.10
% Grading Choice	71	85	86	86	

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[a] Total ration phosphorus and phytase units (FTU), DM basis.
[b] 1 = standard, 2 = select, 3 = choice

If phytase activity is adequate in ruminants, then there should be no differences exhibited between the 0.29% P and 0 FTU phytase treatment and the treatments receiving phytase supplementation in apparent digestibility of phosphorus. In this experiment, steers receiving the 0.31% P and 200 FTU phytase treatment had a lower apparent digestibility of all minerals analyzed than did steers receiving the 0.29% P and 0 FTU phytase treatment. However, steers receiving the 0.32% P and 400 FTU phytase treatment exhibited the greatest apparent digestibility when compared to all treatments for all minerals analyzed.

Experiment 4. Phosphorus and Microbial Phytase Apparent Digestibility Trial

Table 20 presents apparent digestibility means for phosphorus, calcium, magnesium, copper, and zinc for steers supplemented with either: 1) 0.28% P and 0 FTU phytase, 2) 0.28% P and 250 FTU phytase, or 3) 0.28% P and 500 FTU phytase. No supplemental phosphorus was added to treatments to see if there was an improvement in mineral apparent digestibility when microbial phytase was supplemented to a corn based finishing diet. There were no differences ($P>0.05$) between treatments for feed or fecal minerals, but steers receiving the phytase supplements had a greater fecal output of phosphorus than did the steers which were not supplemented. These findings are in agreement with those of experiment 4.

There were no significant differences between the 0.28% P and 250 FTU phytase treatment and the 0.28% P and 0 FTU phytase treatment for apparent digestibilities of phosphorus, calcium, magnesium, copper, or zinc. However, both treatments exhibited significantly lower apparent digestibilities for phosphorus, calcium, magnesium, and copper than the 0.28% P and 200 FTU phytase treatment. Apparent digestibilities followed the same pattern as seen in Experiment 3 (table 19) with the exception of copper, and zinc. The 0.28% P and 500 FTU phytase treatment had the highest ($P>0.05$) apparent digestibility for phosphorus, calcium, and magnesium, followed by the 0.28 % P and 0 FTU phytase (table 20). Consistent with the results in Experiment 3, the 0.28% P and

TABLE 19. Least square means for feed, fecal, and apparent digestibility of phosphorus (P), calcium (Ca), and magnesium (Mg) of finishing steers supplemented with different levels of phosphorus (P) and phytase.

	Treatment				
Item	0.29%P and 0 FTU phytase^{a}	0.31% P and 200 FTU phytase^{a}	0.32% P and 400 FTU phytase^{a}	0.35% P and 0 FTU phytase^{a}	SEM
Feed Mineral Content^{b}					
% P	0.29^{c}	0.31^{c}	0.32^{f}	0.35^{d}	0.003
% Ca	0.48	0.57	0.61	0.60	0.09
% Mg	0.21	0.28	0.29	0.21	0.03
Cu, ppm	9.00	13.00	12.95	12.55	0.92
Zn, ppm	69.20	100.40	96.35	81.35	8.60
Fecal Mineral Content^{b}					
% P	0.55^{c}	0.66^{c}	0.60^{c}	0.83^{d}	0.03
% Ca	1.93	1.79	2.26	1.09	0.54
% Mg	0.58	0.47	0.58	0.56	0.04
Cu, ppm	30.45	31.90	36.35	35.70	2.63
Zn, ppm	231.00^{bc}	245.80^{bc}	200.80^{d}	224.10^{bcd}	6.98
Apparent Digestibility					
% P	80.61^{c}	69.61^{d}	90.45^{c}	51.32^{d}	6.80
% Ca	61.68^{c}	58.84^{d}	79.96^{c}	56.43^{d}	6.18
% Mg	71.16^{c}	66.89^{c}	89.63^{c}	44.09^{d}	11.80
% Cu	62.67	57.93	85.66	40.71	13.55
% Zn	64.40	63.51	86.79	42.10	13.13

Total ration phosphorus and phytase units (FTU), DM basis

[b] Mineral content on DM basis.

[c,d] Means in a row with different superscripts differ ($P<0.05$).

250 FTU phytase treatment exhibited apparent digestibility means signicficantly greater than the 0.28% P and 0 FTU treatment. In this experiment, the differences between the two treatments were not as dramatically large. One explanation for this difference between the two experiments could be the method of application. In experiment 3, phytase was incorporated into the diet as a dry pellet whereas in the present experiment, phytase was first mixed with water to form a slurry, then mixed with the diet. Phytase, like other enzymes are sensitive to moisture and degrade when exposed to it. However, mixing phytase with water is an industry-accepted method of applying phytase to a feedstuff. During this experiment, phytase was mixed daily and immediately prior to feeding to ensure that only minimal degradation occurred. Even though the difference between the apparent digestibilities of the treatments used in this experiment were not as great as in experiment 3, the pattern of the high phytase supplement exhibiting a greater apparent digestibility than the unsupplemented treatment remained. This experiment supports the results seen in experiment 3. From the results of both experiments, it can be concluded that the addition of microbial phytase to a corn-based diet does improve apparent digestibility of phosphorus in ruminants, which is predominantly in the form of phytate phosphorus.

To examine the effects of supplementing or not supplementing phosphorus on feedlot performance, slaughter data and apparent digestibility, all three feedlot trials were combined into two treatment groups, 0.35% P and 0.26% P (tables 21, 22, 23). Cattle supplemented with phytase were not included in this study. Seven hundred twelve steers were used in this analysis. There were no differences (P>0.05) between the two treatment groups in initial and final weights (table 21). Treatment groups did not differ in overall DMI, ADG, or feed to gain ratio (table 21). Cattle not receiving supplemental phosphorus showed a slight, however not significant ($P>0.05$), advantage in feed efficiency (5.76 vs. 5.81, 0.26% P and 0.35% P, respectively). These findings are in agreement with those of Erickson et al. (42) who reported that phosphorus supplementation was not needed for maximal gain and bone maintenance of finishing steers.

Table 22 presents slaughter data for all three feedlot studies. Only 503 steers were analyzed due data not being collected on 95 steers during experiment 1. There were no significant differences seen for hot carcass weights, dressing percents, or yield grades between steers supplemented with phosphorus and steers not supplemented with phosphorus. Dressing percents differed by only 0.56% between treatment means. The percent of cattle grading choice was not included in this analysis due to the potential influence of different implants used in the experiments. Table 23 presents the feed, fecal, and apparent digestibility means for the combined data from experiment 1, 2, and 3. Fecal data was not collected during experiment 1. Feed phosphorus content was significantly different between treatments and as was fecal phosphorus. There were no differences between calcium or magnesium feed contents between treatments. Steers not supplemented with phosphorus excreted more calcium and magnesium than did supplemented steers, however these differences were not significant. As seen in the preceding experiments, steers supplemented with phosphorus had greater ($P<0.05$) fecal phosphorus levels than steers not supplemented with phosphorus (0.80% vs. 0.58%, respectively).

TABLE 20. Least square means for feed, fecal, and apparent digestibility of phosphorus (P), calcium (Ca), and magnesium (Mg) of steers supplemented with different levels of and phytase.

	Treatment			
Nutrient Specifications, % DM	0.28 % P and 0 FTU phytase[a]	0.28 %P and 250 FTU phytase[a]	0.28 % P and 500 FTU phytase[a]	SEM
Feed Mineral Content[b]				
% P	0.28	0.28	0.28	0.01
% Ca	0.68	0.55	0.53	0.08
% Mg	0.16	0.16	0.17	0.01
Cu, ppm	14.00	9.97	12.08	2.46
Zn, ppm	39.27	29.29	35.40	4.42
Fecal Mineral Content[b]				
% P	0.76	0.81	0.85	0.07
% Ca	2.20	2.21	2.22	0.18
% Mg	0.38	0.40	0.39	0.29
Cu, ppm	31.85	33.80	30.40	1.57
Zn, ppm	132.97	140.65	134.72	1.57
Apparent Digestibility				
% P	57.51[c]	57.19[c]	66.94[d]	6.08
% Ca	50.02[c]	50.28[c]	65.09[d]	6.35
% Mg	63.55[c]	62.88[c]	73.02[d]	4.47
% Cu	62.73[c]	34.48[d]	61.50[c]	8.27
%Zn	50.87	51.32	59.16	9.10

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[a] Total ration phosphorus and phytase units (FTU), DM basis.

[b] Mineral content on DM basis.

[c,d] Means in a row with different superscripts differ ($P<0.05$).

TABLE 21. Least square means for growth performance for feedlot steers fed different levels of phosphorus (P)[a].

	Treatments		
Item	0.26% P[b]	0.35% P[b]	SEM
No. Pens	30	30	
No. Steers	357	355	
Initial wt, kg	297	296	3
Final wt, kg	566	565	18
DMI, kg/d per head	9.22	9.30	0.13
ADG, kg/d per head	1.69	1.71	0.01
Feed to Gain Ratio	5.76	5.81	0.12

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[a] Average of main phosphorus effects for all three feedlot studies.
[b] Total ration phosphorus level, DM basis.

TABLE 22. Least square means for slaughter data for feedlot steers fed different levels of phosphorus (P)[a].

	Treatments		
Item	0.26% P[b]	0.35% P[b]	SEM
No. Pens	30	30	
No. Steers	262	241	
Hot Carcass Weight, kg/head	340.94	344.94	3.39
Dressing %	60.08	60.64	0.28
Yield Grade	2.41	2.37	0

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[a] Average of main phosphorus effects for all three feedlot studies.
[b] Total ration phosphorus level, DM basis.

TABLE 23. Least square means for feed, fecal, and apparent digestibility of phosphorus (P), calcium (Ca), and magnesium (Mg) for feedlot steers fed different levels of phosphorus (P)[a].

	Treatments		
Item	0.26% P[b]	0.35% P[b]	SEM
Feed Mineral Content[c]			
% P	0.26[d]	0.35[e]	0.01
% Ca	0.59	0.52	0.03
% Mg	0.23	0.22	0.02
Fecal Mineral Content[c]			
% P	0.58[d]	0.80[e]	0.06
% Ca	1.98	1.60	0.37
% Mg	0.54	0.45	0.04
Apparent Digestability[c]			
% P	84.18[d]	64.21[e]	4.40
% Ca	72.26[d]	46.77[e]	5.27
% Mg	80.80[d]	63.80[e]	5.06

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[a] Average of main phosphorus effects for all three feedlot studies.
[b] Total ration phosphorus level, DM basis.
[c] Mineral content on DM basis.
[d,e] Means within the same row differ ($P<0.05$).

When combining the data from all three studies into either supplemented or not supplemented treatments, the difference seen between apparent digestibility is significant (table 23). This effect was evident in all three previous studies, however, when combined in this manner, it is more apparent. Steers that did not receive phosphorus supplementation exhibit a greater ($P<0.05$) apparent digestibility for phosphorus, calcium, and magnesium. This effect was also seen when each experiment was presented individually and cannot be readily explained by a phosphorus level effect on calcium or magnesium digestibility.

Multiplying the phosphorus content of the diet by the apparent digestibility results in the same percent phosphorus apparently absorbed by the steers (0.22% vs. 0.22%, 0.35%P and 0.26% P, respectively). Calculating with calcium and magnesium resulted in an improvement with the 0.26% P treatment group (0.38% vs. 0.28% and 0.18% vs. 0.15%, calcium and magnesium, respectively).

Phosphorus absorption is via both a passive and an active transport mechanism (1). Active transport is the major route of phosphorus absorption only in the presence of a dietary deficiency of phosphorus. Passive absorption is mass driven; phosphorus absorption increases linearly with increases in dietary phosphorus levels. From the data presented, two explanations can be proposed. The first explanation is that a threshold for phosphorus absorption is reached at 0.22% P in the diet and any phosphorus present above that amount is not absorbed. The second explanation is that the 0.26% P diet is marginally deficient and active transport becomes the major route for phosphorus absorption and this mechanism's kinetics improve the efficiency of phosphorus absorption. Either way would manifest itself as an improvement in apparent digestibility.

From the data presented, it can be concluded that supplementing phosphorus is not beneficial in improving feedlot performance or slaughter data. There is an improvement seen in fecal phosphorus output and the apparent digestibility of phosphorus when supplemental phosphorus is not added to the diet above NRC (82) requirements (82). The addition of microbial phytase to a corn based diet did improve the apparent digestibility of phosphorus, however fecal phosphorus output was increased. The improvement in the apparent digestibility of phosphorus by the addition of phytase to the diet indicates that ruminants, even though possessing phytase activity by virtue of rumen bacteria (112), do exhibit enhanced phytase activity by the addition of microbial phytase.

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