Fecal Phosphorus Characteristics of Forage-Fed Beef Cattle

Elizabeth Alice Riley

Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science
in
Animal and Poultry Science

Scott P. Greiner, chair
Mark A. McCann
Katharine F. Knowlton

September 27, 2012
Blacksburg, VA

Keywords: phosphorus, beef cattle, forage

Fecal Phosphorus Characteristics of Forage-Fed Beef Cattle

Elizabeth Alice Riley

ABSTRACT

Phosphorus loads in waterways are a focus of environmental concern. Animal agriculture's contribution to this problem has been documented and efforts are focused on mitigating the issue. The effect of increasing amounts of mineral P supplementation on fecal P characteristics was studied in forage fed beef steers. Eight Hereford steers were fitted with total fecal collection bags and fed four diets with a low P grass hay and supplemented with increasing amounts of a mineral source of P, dicalcium phosphate. Dietary DM P concentrations were 0.10 (no P supplementation), 0.23, 0.34, and 0.45% P. Manure was sampled and dried, followed by analysis for total P and inorganic P ($P_i$). Blood was collected via jugular venipuncture following each collection period and plasma $P_i$ was quantified. Total fecal P increased linearly with increasing dietary P concentration: 6.44, 10.6, 16.1, and 18.8 g/d ($P < 0.0001$). Fecal $P_i$ increased linearly with increasing dietary P concentration: 1.58, 2.43, 2.74, and 3.84 g/d ($P = 0.0119$) Manure P solubility, however, did not increase with increasing dietary P concentration: 23.6, 22.3, 17.3, and 20.2% ($P = 0.3646$). Plasma $P_i$ increased linearly with increasing dietary P ($P = 0.0047$). ADG and G:F were not affected by increasing dietary P content. Reducing or eliminating mineral P supplementation to forage fed beef animals is possible, if forage base proves to be adequate in P. Reducing dietary P reduces fecal P excretion and the pollution potential in ecologically sensitive areas like the Chesapeake Bay watershed.

Keywords: phosphorus, beef cattle, forage

## TABLE OF CONTENTS

## LIST OF TABLES



## LIST OF FIGURES

# LITERATURE REVIEW

## I. Phosphorus impacts on soils, waterways.

Phosphorus (P) is an important nutrient for plant and animal growth. It has long been recognized as an essential mineral to maintain healthy, profitable crops and livestock. However, P can also accelerate eutrophication by increasing the biological productivity in surface waters (Sharpley et al., 2003).

Eutrophication, also referred to as algal bloom, has been identified as a primary cause of surface water pollution (EPA, 2010b). Eutrophication pollutes surface water due to the uncontrolled growth of undesirable algae and aquatic weeds, which in turn causes oxygen deprivation and can harm aquatic vegetation and wildlife populations. Although other nutrients, primarily nitrogen and carbon, also accelerate the growth of algae and aquatic weeds, their exchange between atmosphere and water is difficult to control (Sharpley et al., 2003).

The Chesapeake Bay is an ecologically sensitive area that has known challenges regarding nutrient overloads and eutrophication. Chesapeake Bay tributaries and watershed regions, in particular, have been linked to excess nutrients in polluted waters (Sharpley et al, 2003). The EPA estimates that the state of Virginia contributes 43% of the total P loading in the Chesapeake Bay (EPA, 2010). Therefore, controlling P inputs in Virginia waterways is the primary target to reduce eutrophication and pollution.

Agriculture represents 22% of the land used in the Chesapeake Bay watershed area and has been identified as the single largest contributor of nitrogen, P and sediment loads to the Bay through fertilizer and manure application, along with tilling (EPA, 2010).

Confinement animal feeding operations (CAFOs) have represented a target for nutrient management improvement. The EPA defines beef cattle CAFOs as the confinement of animals for 45 days in a 12-month period with no grass or vegetation in the confinement area during the normal growing season. In addition, the number of animals in confinement determines the level of regulation (EPA, 2012). These agricultural systems are an important part of many rural economies. The manure generated from CAFOs can be a valuable source of nutrients for cropland. However, animal management and feeding practices can often yield an imbalance in P inputs and outputs, as well as an imbalance in essential calcium:phosphorus ratios exceeding those required for plant growth (Gollehon et al., 2001). Large levels of P and other nutrients in manure from CAFOs often require larger landmass to adequately disperse the nutrients according to plant needs, increasing transportation costs and other inputs (Powell et al., 2001). Nutrient management plans, required for CAFOs, are based on N and P levels. Balancing wastewater and manure nutrients applied to the land with the nutrient needs of the crop is a critical part of a nutrient management plan (EPA, 2011).

The increased specialization and intensification of livestock and farming systems in recent years have increased nutrient management concerns. In intensive animal production, P inputs are chiefly feed, rather than fertilizer. This can increase P inputs in a farming system (Sharpley et al., 2003). Phosphorus surpluses in farming systems have increased in conjunction with the concentration of animal feeding operations and the intensification of agriculture. Often, a concentration of CAFOs in an area can lead to nutrient accumulation in the soil that exceeds crop requirements (Sharpley and Moyer, 2000).

Recent EPA proposals regarding total maximal daily loads (TMDL) indicate increased scrutiny of animal agricultural production (EPA, 2010b). Total maximal daily load is the amount of pollutant a waterway can receive and still meet water quality standards (EPA, 2010b). While government regulation has historically focused on CAFOs, grazing beef systems represent a non-point source of pollution in the Chesapeake Bay watershed area. The EPA (2010a) defines non-point source pollution as coming from a variety of diffuse sources, not a "discernable, confined and discrete conveyance." There are approximately 400,000 beef cattle in Virginia's Chesapeake Bay watershed counties (Virginia Annual Statistical Bulletin, 2010). These cattle are often supplemented with a free choice mineral that contains P, and are often grazing in fields with adequate or high levels of soil P.

Animal manures contain several nutrients important to plant growth, emphasizing their value as fertilizers in agricultural systems. Loss of these nutrients to waterways not only creates environmental problems, but also represents an economic loss to farmers.

Moreover, some forms of nutrients are more biologically available to plants, and thus more likely to cause water quality issues, than others. Water soluble P (WSP) is associated with dissolved-reactive P in soils, a P form that is directly taken up by plants (Kleinman, 2002). Animal manures contain several fractions of P, the most relevant being inorganic P ($P_i$), a water soluble form, and total P (TP). A more detailed description of fecal P fractions can be found in Section IX.

While it has been established that grazing beef cattle excrete several forms of P and can, therefore, contribute to P overloading in waterways, there are a myriad of ways to mitigate and reduce this contribution. Solutions like fencing off stream access, utilizing rotational grazing, progressive pasture management, and nutrient management have all proven to be effective in reducing P deposition into waterways.

In recent years, animal nutrition has been identified as a means to reduce N and P losses to the environment (Knowlton et al., 2004). Improved understanding of P digestion and absorption as well as improved animal management can reduce the P content of manure as well as related economic and environmental losses. Some studies have demonstrated that over the long term, reducing or eliminating mineral P supplementation to grazing animals has no ill effects on reproductive and growth parameters, provided that the animal's P needs are met through the forage base (Brokman et al., 2008; Cohen, 1972). The historical perception that reproductive performance and P supplementation are correlated contributes to the idea that P needs to be supplemented.

**II. Importance of P in beef diets.**

Phosphorus is a macromineral that is essential in the beef animal diet. It is one of the most versatile mineral elements in the body, involved in a variety of important functions, chief among them bone formation and structure. As an animal grows and matures, ossification of the bone progresses and the proportion of P in the skeleton increases. Phosphorus contained in the skeleton, about 18% P, makes up an important reserve of the mineral for animal use in conditions of deficiency (Karn, 2000; Pond et al., 2007).

Because Ca and P are both constituents of bone, their dietary interaction is worth noting. Optimal performance in beef animals occurs when the ratio of Ca to P between 1.5:1 and 2:1. If this ratio becomes unbalanced, meaning there is an excess of Ca, or deficiency of P, reduced growth, feed efficiency and reproductive parameters can develop in addition to reduced absorption of P (Ternouth, 1990, Lardy, 2005). On the other hand, if P intake exceeds Ca, urinary calculi can develop (Lardy, 2005).

Phosphorus is an important component of a variety of metabolic and cell regulation processes. It is essential for a wide range of energy metabolism and transfer pathways as a constituent of molecules like adenosine triphosphate (ATP), adenosine diphosphate (ADP), adenosine monophosphate (AMP), and creatine phosphate. Phosphorus is also essential for genetic information transfer and buffering systems. Phospholipids are a vital component of animal cells, regulating and maintaining cell structure and integrity, and are an integral part of myelin, which sheaths the nerves (Karn, 2000).

Salivary P functions in two primary ways: as a buffer to prevent large swings in pH from organic acid production and as a source of P for ruminal and gastrointestinal microbes (Ternouth, 1990). Salivary P is not considered a good indicator of overall P status, but can be indicative of absorbed P (Karn, 2001). Gartner et al. (1983) asserted that blood components plasma and serum are more sensitive to P deficiency conditions than saliva. Blood components are not good indicators of overall P status due to their biological variability, but are generally reflective of P intake (Gartner et al., 1982; Read et al., 1986).

Phosphorus is an essential requirement for ruminal and gastrointestinal microbes (Preston and Pfander, 1964). Studies have shown that when inorganic P levels are less than 50-80 mg/L, gut microbial activity is diminished due to reduced fiber digestion (Komisarczuk et al., 1986). Depressed weight gains and feed efficiency associated with low P and P deficient diets could be due, in part, to impaired rumen microbial function (Komisarczuk et al., 1986).

Hormonal regulation of P in the animal is important, but not to the same extent as Ca. Three hormones, parathyroid hormone (PTH), calcitonin (CT), and di-hydroxy-cholecalciferol (DCC), have been shown to have some impact on P absorption, deposition, and/or excretion, but the literature suggests that the impact of these hormones are of little practical significance in beef cattle (Karn, 2001; Riad et al., 1987).

Phosphorus homeostasis in ruminants is achieved primarily through endogenous fecal losses (Challa et al., 1988). Challa et al. (1988) also concluded that bone resorption, salivary P secretion, P absorption and urinary P excretion all contribute to P homeostasis in growing calves. The relative importance of these mechanisms can vary due to stage of production or dietary source of P. Salivary and small intestinal P levels help maintain P homeostasis in the body, but it doesn't appear that one or the other solely controls endogenous excretion (Scott et al., 1983) The mechanism seems to lie in absorptive efficiency. According to Scott et al. (1983), when P absorption in the small intestine keeps pace with saliva P secretion, P balance is maintained. When this P balance between salivary and absorbed small intestine P is not maintained, then fecal P excretion exceeds rates of dietary P intake.

A short-term deficiency of P may be overcome by gastrointestinal recycling of P or bone P utilization. If a deficiency persists over a course of weeks or months, however, beef producers can face significant losses. The primary symptom is reduced feed intake, which can cascade into reduced weight gain, feed efficiency, nutrient absorption, and bone demineralization. Reduced reproductive performance (low ovarian activity and low conception rates) has been observed in P deficient animals, but it is not known if this is directly linked to the P deficiency or a result of reduced feed intake and performance (Ternouth, 1990). Maas (1987) concluded that macromineral deficiencies are not a major cause of decreased reproductive performance in beef cattle. Rather, energy should be the focus for optimum reproductive performance (Maas, 1987).

This association with reproductive performance may contribute to producer overfeeding of P. For example, if a drop in reproductive performance is noted, many producers might increase their P supplementation hoping to correct it. As noted above, it is not clear if the P deficiency itself or the reduced energy intake is the cause of the impaired reproductive performance. Wu et al. (2000) concluded that reproductive performance of high producing dairy cows did not suffer when fed a low P diet.

**III. Evaluating beef cattle NRC requirements for P.**

Phosphorus requirements for growing and finishing beef cattle are published by the National Research Council and are calculated using the factorial method and are based on body weight and desired rate of gain (NRC, 1996).

Phosphorus and Ca absorption and metabolism, and by extension, the beef cattle requirements and supplementation needs, are influenced by many variables including variability of nutrients, availability of those nutrients, energy level of the feed and disease and environmental stress, and biological output, gain and milk (McDowell, 2003).

Wise et al. (1958) conducted a classic study to estimate the P requirement of growing calves. They utilized 40 male Holstein calves and fed 4 diets in increasing quantities of P (0.09%, 0.12%, 0.18% and 0.30% diet DM, respectively). Feed intake, bi-weekly weights as well as bone growth and bone ash parameters were measured. The authors report that the basal ration at 0.09% P was nutritionally adequate except for P. The authors also reported that feed intake and weight gain were favorable in calves fed the higher P diets, at 0.18% and 0.30% P. They asserted the P requirement to be slightly higher than 0.18% diet DM. Moreover, they suggested including a margin of safety and concluded 0.30% P be required for growing calves.

Recently, it has been suggested that these historical P requirements may have overestimated the actual P requirements for growing and finishing cattle. Erickson et al. (1999) hypothesized that the P requirement for beef cattle is overestimated. To test their hypothesis, 60 steers were fed ten diets with P levels varying from 0.14% to 0.34% and Ca levels were either 0.35% or 0.70%. The authors found no interaction between Ca and P and reported that there were no differences in DMI, ADG, and feed efficiency nor bone density or mineral parameters among treatments.

The authors concluded that the NRC requirement for P is overestimated. The NRC requirement was 0.20%, but the authors saw no detrimental effects on normal growth and bone parameters, so they suggest that the requirement is less than 0.14%, the lowest dietary P concentration that was fed. The authors estimate the industry average for P intake is 0.35 to 0.39%. Overall, the authors concluded that a corn-based finishing diet is more than adequate to meet a steer's P needs, and mineral P supplementation is not necessary in most cases, given environmental concerns surrounding P.

A margin of safety is often included in animal diets to factor in variation in diet quality and components, nutrient demands, and other factors that might influence how much of a particular nutrient or mineral is needed. Additionally, a beef animal's P requirement is dynamic throughout its life and even throughout an annual production cycle; it changes according to physiological state, which is often in flux. From a production standpoint, it is often easier to purchase a trace mineral salt that will work for every beef animal on a farm at a given time. It is often not possible or practical to have different mineral supplements for every animal in a given nutritional state. The solution, however imperfect, is to supply P that is adequate for all physiological stages.

Table 1. NRC requirements for beef cattle at different stages of production

| | Beef cattle stage of production | | |
|---|---|---|---|
| P required, g/d | 300 kg, growing and finishing cattle, 0.5 kg gain/d | Pregnant replacement heifers, 6 mo. pregnant | Beef cows 60 months, 8 kg peak milk, 2 mo. since calving |
| Maintenance | 7 | 9 | 13 |
| Growth | 5 | 3 | 0 |
| Lactation | 0 | 0 | 11 |
| Pregnancy | 0 | 0 | 0 |

| Total | 12 | 13 | 24 |
| --- | --- | --- | --- |

**IV. Forage uptake of P.**

Plants require P for similar reasons that animals do—namely, energetic processes and as a component of genetic information transfer. The form of P available to plants is referred to as dissolved reactive P (DRP) (Kleinman et al., 2005). Uptake of P by plants is primarily influenced by two factors: P tends to be chemically unavailable, being bound by Al and Fe in very acidic soils and by Ca and Mg in alkaline soils. The other factor is the slow movement and low solubility of P in soils. In this regard, P uptake can be a function of root depth and soil temperature (Bittman, 2009). Logically, young plants with shallow roots and in colder soils are often lacking in P, and development and maturation may be delayed. Phosphorus deficiency in crops is hard to correct in the current growing season (Bittman, 2009).

Manure application is a cost effective way of providing nutrients, improving soil structure, and increasing vegetative cover. In areas where P overloading in soil and waterways is a concern, P-based (as opposed to N-based) manure application has been effective in maintaining safe and consistent P levels in the soil annually. Most manure types have a lower N:P ratio (3:1, for example) than the N:P uptake ratio for most plants (corn is 6:1) (Eghball, 2005). This indicates that N and P are more concentrated in most manure types, requiring larger land areas to distribute them safely.

Animal manure contains a significant amount of nutrients that can be utilized for crop production. Manure is typically utilized when a growing crop is in need of nitrogen. With surface water pollution and eutrophication concerns, P-based application strategies have become increasingly common (Eghball, 2005). Inorganic phosphorus that is found in animal manures is plant available.

Forage uptake of P is dependent on a variety of environmental factors. Fertilizing pastures with manure can improve soil structure, fertility and plant nutrient content. Animals excrete a form of P that is plant available, so care must be taken to ensure that P overloading does not occur in land areas and waterways.

**V. Content and availability of P from forage sources.**

Content and availability of forage P is primarily based on stage of maturity and presence of the organic molecule phytate, or phytic acid. In most cases, P content declines as forages mature (McDowell, 2003). Additionally, well-fertilized forage stands typically contain high levels of P (Pederson et al., 2002). Phosphorus is not evenly distributed throughout a plant.

The beef cattle NRC reports that the assumed absorption coeffecient for P in both grain and forage sourcs to be 0.68 (NRC, 1996). The dairy cattle NRC offers a more nuanced view, reporting that the assumed absorption coffecient for P in forages is 0.64 for forages and 0.70 for grain sources (NRC, 2001). Recent studies have suggested that there is more variability in the absorption coeffecient, even within forage sources (Cherry et al., 2010).

Phytate is a molecule that contains much of the P in a forage source. Phytate, which is an inositol ring surround by six phosphate molecules, can hinder intestinal absorption of P, Ca, and other elements. Phytate P is generally biologically unavailable to nonruminants. In ruminants, however, microbes in the rumen synthesize phytase, which hydrolyzes the phytate and releases the phosphate molecules for biological use. Strides have been made recently in creating microbial phytases for use in nonruminants, making P more biologically available (McDowell, 2003). The use of microbial phytase in nonruminant diets can reduce their need for inorganic P supplementation and can result in a 30 to 50% reduction in P excretion (Bedford, 2000; Poulson, 2000). Even animals, ruminants and nonruminants, that consume all organic sources of P are able to excrete water-soluble P. The phytate molecule present in forage is organic, but all of phosphate groups released by phytase are inorganic. These unabsorbed phosphate molecules that are excreted are considered fecal $P_i$. Though phytate releases the phosphate molecules, absorption can vary according to feedstuff.

Determining the biological availability of P in forage, grain and other organic sources of P is difficult, there being no comprehensive, inexpensive test readily available (Dou et al., 2002). The wide variability in P content and the nutritive quality of feedstuffs contributes to built in margins of safety in mixed rations, thus contributing to overfeeding.

**VI. Mineral P availability.**

If forage and other dietary sources do not provide adequate P, mineral supplementation is the most common option to meet P requirements. The form and availability of these mineral supplements can impact absorption of P. Compared to forage and grain, mineral sources of P are considered highly biologically availability.

Several inorganic P sources are available for supplementation. Mineral P sources considered readily biologically available include dicalcium phosphate (dical, $CaHPO_4$), ammonium phosphate ($NH_3PO_4$) and sodium phosphate ($NaPO_4$) (Peeler, 1972). Of these, dicalcium phosphate is the most commonly used and commercially available. Peeler (1972) reports that while mineral sources of P generally have a higher absorption coefficient than organic sources, there is variation, simply due to the chemical form of P found in the supplement. These figures often range from 80 – 100% availability. Other factors that contribute to mineral P availability are particle size and feed processing.

Odongo et al. (2007) evaluated the long term effects of feeding dairy cows diets without mineral P supplementation. The trial lasted until two lactations were complete or the cow was culled. The authors found no effect on milk production or reproductive performance, suggesting that the forages and grain used contained adequate amounts of P to sustain performance in high-producing dairy cows. The authors do recommend, however, some supplementation might be necessary for heifers in first lactation (Odongo et al., 2007).

Brokman et al. (2007) demonstrated that grazed forage provided adequate P for growing Holstein steers. During a two year study, the authors observed no detrimental effects on performance when mineral P supplementation was removed. The pasture utilized was managed in a way that resulted in high quality forage with adequate protein (19%) and P (0.32% of forage DM). The protein and P provided from forage was above published requirements, therefore BW gains would not be expected from additional P supplementation. The authors recommended that no mineral P supplementation was necessary for stocker-type cattle in areas with high soil and forage P.

Although taking a slightly different approach, Loxton et al. (1983) also noted that P provided from fertilized pasture was adequate for gestating and lactating cows. The authors do not report details of the fertilizer but indicate that there was no significant difference in the nitrogen content of the two pastures. Forage P levels were consistently higher in the fertilized pasture. Utilizing two groups of cows, one pasture base was fertilized and one was not. The authors observed superior weight gains of both cows and calves on the fertilized pasture. They hypothesized that the increased performance is a result of higher DMI from increased P intake. Mineral supplementation was not provided to either group.

**VII. Phosphorus partitioning in the beef animal.**

It is estimated that 80-85% of total P and 99% of Ca in the animal body is contained in bone (McDowell, 2003). These two minerals are present as hydroxyapatite $Ca_{10}(PO_4)_6(OH)_2$ (Ternouth, 1990). In times of deficiency, beef cattle mobilize up to 30% of both minerals from bone.

In soft tissues, P is primarily concentrated in red blood cells, muscle, and nerve tissues, largely in organic forms consisting of phospholipids, phosphoproteins, nucleic acids, and some hormonal messengers and regulators. The gastrointestinal tract contains large quantities of secreted and resabsorbed P, a store that is readily available and may constitute as much as 3.0% of total body P (Ternouth, 1990).

In beef cattle, unabsorbed P is excreted primarily via the feces, with minimal urinary loss (Block et al., 2004; Geisert et al., 2010). Beef animals fed a high concentrate diet, however, have reported higher urinary P losses, though fecal P still represents the majority of P loss (Block et al., 2004). Phosphorus losses in the feces result primarily from unabsorbed salivary P, although some is attributed to the natural sloughing of cells from the intestinal tract (Block et al., 2004; McDowell, 2003; Ternouth, 1990).

In the beef animal, P is primarily found in the skeleton, with soft tissues accounting for a smaller proportion of total P. Phosphorus that is not utilized or absorped is excreted primarily through the feces with a very small amount lost through the urine, although this has can depend on the diet of the animal. Beef animals consuming a high concentrate diet still excrete P primarily via feces, but urinary P can represent a larger loss than that from cattle on a forage based diet.

**VIII. Dietary management of P.**

Phosphorus is the most expensive macromineral to supplement, representing more than half of the cost of mineral or vitamin premixes supplied to beef cows (Mehren, 2008). It is estimated that the oversupplementation of P costs the U.S. dairy industry $100 million annually (Satter et al., 2002). Erickson et al. (1998) asserted that mineral P supplementation in finishing diets is an unnecessary economical and environmental cost and should be discontinued. Typical finishing diets in beef cattle contain high amounts of concentrates and concentrate by-product feeds to accommodate energy and protein demands. These feedstuffs are also typically high in P, which may eliminate the need for mineral supplements altogether (Geisert et al., 2010). By-product and co-product feeds, resulting from both wet and dry milling industries, are usually very economically priced and an excellent source of energy and protein (Stock et al., 2000). When energy demands peak in early lactation, beef producers often chose to supplement such a feedstuff in their rations. Phosphorus demands also peak at this stage.

Many studies have demonstrated that the dietary content of both N and P has a direct effect on the quantity of N and P excreted in manure (Satter et al., 2002). A closer look at the P requirements for beef cattle should be called for, in addition to reducing or eliminating P supplementation.

The mineral nutritionists in the modern dairy and feedlot cattle industry often advocate for precision feeding of P, rather than estimate or inclusion of safety margins into feed formulations (Geisert et al., 2010; Knowlton et al., 2004). This is appropriate from an environmental standpoint, as well as an economic one. Satter et al. (2002) noted that P fed in excess of the requirement is excreted chiefly in the feces, much of P is water-soluble and therefore plant available. The authors documented a 20% reduction in dietary P resulted in a 25% decrease in manure TP.

Precision feeding of P is more difficult in a grazing beef animal diet, as the only supplement provided is a free choice mineral. This speaks to the importance of routine and consistent forage testing to determine forage P available. If forage stands are fertilized as needed and managed properly, mineral supplementation of P may not be required at all and can decrease the cost of such supplements (Brokman et al., 2007).

Inconsistent recommendations from nutritionists, veterinarians, and extension personnel can influence P overfeeding. This advice may have stemmed from the mistaken belief that overfeeding P was seen as "cheap reproductive insurance" (Knowlton et al., 2004). In recent years, however, researches have cast doubt on that notion, observing that reduced reproductive performance in a P deficiency is more likely linked with reduced energy intake and DMI (Maas et al., 1987; Ternouth, 1990; Wu et al., 2000).

Researchers note that a reduction in manure P greatly reduces the amount of land required to utilize the nutrients contained in the manure, fertilizing only to the plant needs and helping mitigate P loads in waterways and streams (Erickson et al., 2002; Knowlton et al. 2004; Satter et al., 2002).

**IX. Fractions of P in beef feces.**

In the ruminant, P is primarily excreted through the feces (Block et al., 2004; Cohen, 1973). The relationship between dietary P and fecal P is linear (Geisert et al., 2010). A variety of forms of P exist in manure, all of varying availability to plants. Total P is comprised of inorganic and organic forms of P. Organic can be further subdivided into residual P (nucleic acid-type material), acid soluble organic P ($P_{aso}$, inositol hexaphosphates), and phospholipids (Barnett, 1993).

Barnett (1993) updated the existing literature on P forms in animal manure by analyzing a variety of animal manures from multiple farms and studying the forms of P present and their environmental implications. Manure samples from dairy, feeder cattle, feedlot cattle, swine, broilers, and layers were obtained and analyzed. In all manures, $P_i$

represented a large proportion of TP, 49.6% on average. In most cases, broiler litter being the exception, $P_i$ represented the majority of P present. Feeder cattle and feedlot cattle manure contained 47.1% and 48.3% $P_i$, respectively. The author states that the diets of the beef cattle were varied in their ingredients and nutritional content. Dairy cattle had the highest average proportion of $P_i$ at 63.2%. The author found the values of the portions of P found in collected feces to be considerably higher than historical literature values. $P_i$ is the most critical component of TP in manure, as plant response is dependent on it (Barnett, 1993). Decreasing this water soluble portion is critical to decreasing the risk of pollution in waterways.

Increasing dietary P concentrations results in a greater amount of $P_i$ (Dou et al., 2002). Regardless of dietary source (organic vs. inorganic, forage vs. concentrate), fecal $P_i$ dominates the fecal fraction of P (Dou et al., 2002).

Other researchers have divided the P fractions in feces differently. Spiekers et al. (1993) categorized fecal P into three components: unavailable dietary P (dietary P that can't be digested or absorbed), inevitable P loss (primarily microbial residue and metabolic P, what has been referred to as endogenous P), and regulated P (a component that varies according to dietary intake relative to cow requirement. Dou and colleagues (2002) suggest that this regulated P is largely, if not completely water soluble as it reflects the portion of P that was consumed in excess of animal requirements.

There is a strong correlation between $P_i$ and dissolved reactive P (DRP) in soils (Kleinman et al., 2002 and Kleinman et al., 2005). Dissolved reactive P is the most associated with environmental P losses, but is a term typically used in soil science. Sharpley and Moyer (2000) demonstrated that the potential for P to be leached from manure and compost was most closely related to water extractable $P_i$. The authors concluded that $P_i$ could be used to estimate the release of P and its potential to enrich waterways.

While researchers classify fecal P forms differently, it has been established that some forms are more plant available than others. The forms of P in animal manure are diet dependent, indicating the importance of nutrition in controlling P excretion.

**CONLUSION**

Phosphorus is an important mineral from animal nutrition, economic, and environmental perspectives. Defiencies of macrominerals like P are less common in modern American agriculture than in previous years. The opposite is now a concern. Overfeeding of P in animal agriculture can have detrimental effects on the environment. In ecologically sensitive areas like the Chesapeake Bay Watershed, a close look at grazing beef animals and common P feeding practices is necessary. To mitigate P overfeeding and consequently, P loading in waterways, the practice of mineral P supplementation to these animals should be scrutinized. If forage P levels are adequate, we hypothesize that mineral P supplementation is not necessary. By observing the fecal P characteristics of beef cattle fed forage and increasing amounts of a mineral P supplement, we can determine the necessity of mineral P supplementation.

## Literature Cited

Barnett, G. M. 1994. Phosphorus forms in animal manure. Biores. Techno. 49:139-147.

Bedford, M. 2000. Exogenous enzymes in monogastric nutrition—They're current value and future benefit. Anim. Feed Sci and Technol. 86:1-13.

Bittman, S. 2009. Forage, phosphorus and soil on dairy farms. WCDS Adv. Dairy Technol. 21:333-347.

Block, H. C., Erickson, G. E., PAS and Klopfenstein, T. J. 2004. Review: Re-evaluation of phosphorus requirements and phosphorus retention of feedlot cattle. Prof. Anim. Sci. 20:319-329.

Brokman, A. M, Lehmkuhler, J. W. and Undersander, D. J. 2008. Reducing phosphorus inputs for grazing Holstein steers. J. Anim. Sci. 86:712-719.

Cherry, N. M., Lambert, B. D. and Muir, J. P. 2010. Ruminal and total tract phosphorus release from feedstuffs in cattle measured using the mobile nylon bag technique. J. Anim. Phys. 94: 665-669

Cohen, R. D. H. 1973. Phosphorus nutrition of beef cattle. 2. Relation of pasture phosphorus to phosphorus content of blood, hair and bone grazing steers. Aust. J. Exp. Agric. and Anim. Husb. 13:5–8

Challa, J., Braithwaite, G. D. and Dhanoa, M. S. 1989. Phosphorus homeostasis in growing calves. J. Agric. Sci. 112:217-226.

Dou, Z., Ferguson, J. D., Fiorini, J., Toth, J. D., Alexander, S. M., Chase, L. E., Ryan, C. M., Knowlton, K. F., Kohn, R. A. amd Peterson, A. B. 2003. Phosphorus feeding levels and critical control points on dairy farms. J. Dairy Sci. 86:3787-3795.

Eghball, B., Wienhold, B.J., Woodbury, B.L. and Eigenberg, R.A.. 2005. Plant availability of phosphorus in swine slurry and cattle feedlot manure. Agron. J. 97:542–548.

EPA. 2010a. Basic Information: What is non-point source pollution? Available: http://www.epa.gov/owow_keep/NPS/whatis.html. Accessed June 2012.

EPA. 2010b. Chesapeake Bay Total Maximum Daily Load for Nitrogen, Phosphorus and Sediment. Available: http://www.epa.gov/reg3wapd/pdf/pdf_chesbay/FinalBayTMDL/CBayFinalTMDLExecSumSection1through3_final.pdf Accessed June 2012.

EPA, 2011. Animal Waste Terms. Available:

http://www.epa.gov/region9/animalwaste/terms.html. Accessed December 2012.

EPA. 2012. What is a CAFO? Available: http://www.epa.gov/region7/water/cafo/index.htm. Accessed September 2012.

Gartner, R.J.W., Murphy, G.M. and Hoey, W.A. 1982. Effects on induced, subclinical phosphorus deficiency on feed intake and and growth of beef heifers. J. Agric. Sci. 98:23-29.

Geisert, B. G., Erickson, G. E., Klopfenstein, T. J., Macken, C. N., Luebbe, M. K. and MacDonald, J. C. 2010. Phosphorus requirement and excretion of finishing beef cattle fed different concentrations of phosphorus. J. Anim. Sci. 88**:**2393.

Gollehon, N., Caswell, M., Ribaudo, M., Kellogg, R., Lander, C., and Letson, D. 2001. Confined Animal Production and Manure Nutrients. U.S. Department of Agriculture. Agriculture Information Bulletin No. 771.

Karn, J. F. 2001. Phosphorus nutrition of grazing cattle: A review. Anim. Feed Sci. Technol. 89**:**133-153.

Kleinman, P. J. A., Sharpley, A. N., Wolf, A. M., Beegle, D. B. and Moore, P. A. 2002. Measuring water-extractable phosphorus in manure as an indicator of phosphorus in runoff. Soil Sci. Soc. Am. J. 66:2009-2015.

Kleinman, P. J. A., Sharpley, A. N., Saporito, L. S., Beegle, D. B. and Wolf, A. M. 2005. Survey of water-extractable phosphorus in livestock manures. Soil Sci. Soc. Amer. J. 69**:**701-708.

Knowlton, K. F., Radcliffe, J. S., Novak, C. L. and Emmerson, D. A. 2004. Animal management to reduce phosphorus losses to the environment. J. Anim. Sci. 82**:**E173-E195.

Komisarczuk, S., Merry, R.J. and McAllen, A.B. 1987. Affect of different levels of phosphorus on rumen microbial fermentation and synthesis determined using a continuous culture technique. Brit. J. of Nutr. 57: 279-290

Maas, J. 1987. Relationship between nutrition and reproduction in beef cattle. Vet Clin. North Am. Food Anim. Pract. 3:633-46.

Mehren, M. 2008. Phosphorus for Beef Cows. Oregon Feed and Grain Association. Available: http://oregonfeed.org/mehren_art_0308.htm. Accessed July 2012.

McDowell, L. R. 2003b. 2nd Ed. Minerals in Human and Animal Nutrition. Elsevier. Amsterdam, The Netherlands

NRC. 2000. 8th Ed. Nutrient Requirements of Beef Cattle. National Academy Press. Washington, D. C.

NRC. 2001. 7th Ed. Nutrient Requirements of Dairy Cattle. National Academy Press. Washingtond, D. C.

Odongo, N. E., McKnight, D., KoekKoek, A., Fisher, J. W., Sharpe, P., Kebreab, E., France, J. and McBride, B. W. 2007. Long-term effects of feeding diets without mineral phosphorus supplementation on the performance and phosphorus excretion in high-yielding dairy cows. Can. J. Anim. Sci. 87:639-646.

Pederson, G. A., Brink, G. E. and Fairbrother, T. E. 2002. Nutrient uptake in plant parts of sixteen forages fertilized with poultry litter: nitrogen, phosphorus, potassium, copper, and zinc. Agron. J. 94:895-904.

Peeler, H. T. 1972. Biological availability of nutrients in feeds: Availability of major mineral ions. J. of Anim. Sci. 35:695-712

Pond, W. G., Church, D. C., Pond, K. R. and Schoknecht, P. A. 2005. 5th ed. Basic Animal Nutrition and Feeding. John Wiley & Sons, Inc. Hoboken, NJ.

Poulson, H.D. 2000. Phosphorus utilization and excretion in pig production. J. Environ. Qual. 29:24-27.

Powell, J. M, Wu, Z. and Satter, L. D. 2001. Dairy diet effects on phosphorus cycles of cropland. J. Soil Water Cons. 56:22-26.

Preston, R. L. and Pfander, W.H. 1964. Phosphorus metabolism in lambs fed varying phosphorus intakes. J. of Nutr. 83: 369-378

Read, M.V.P., Engels, E.A.N. and Smith, W.A. 1986. Phosphorus and the grazing ruminant. 4. Blood and faecal grab samples as indicators of the P status of cattle. S. Afr. J. Anim. Sci. 16:18-22.

Riad, F., LeFaivre, J. and Barlet, J.-P. 1987. 1,25-Dihydroxycholecalciferol regulates salivary phosphate secretion in cattle. J. of Endocrin. 112:427-430

Satter, L. D., Klopfenstein, T. J. and Erickson, G. E. 2002. The role of nutrition in reducing nutrient output from ruminants. J. Anim. Sci. 80:E143-E156.

Sharpley, A. N. and Moyer, B. 2000. Phosphorus forms in manure and compost and their release during simulated rainfall. [Erratum: Nov/Dec 2000, v. 29 (6), p. 2053.]. J. Environ. Qual. 29:2053.

Sharpley, A. N., Daniel, T., Sims, Lemunyon, T. Stevens, J. R., and Parry R. 2003. Agricultural phosphorus and eutrophication. USDA. ARS149.

Stock, R. A., Lewis, J. M., Klopfenstein, T. J. and Milton, C. T. 2000. Review of new information on the use of wet and dry milling feed by-products in feedlot diets. J. of Anim. Sci. 77:1-12.

Ternouth, J. H. 1990. Phosphorus and beef production in northern Australia. 3. Phosphorus in cattle-a review. Trop. Grassl. 24:159-169.

USDA. 2010. Virginia Annual Statistical Bulletin: Livestock and Dairy. Available: http://www.nass.usda.gov/Statistics_by_State/Virginia/Publications/Annual_Statistical_Bulletin/index.asp Accessed June 2012.

Ward, M. and Lardy, G. 2005. Beef Cattle Mineral Nutrition. NDSU Extension. AS-1287.

Wise, M. B., Smith, S. E. and Barnes, L. L. 1958. The phosphorus requirement of calves. J. Anim. Sci. 17:89-99.

Wu, Z., Satter, L. D. and Sojo, R. 2000. Milk production, reproductive performance, and fecal excretion of phosphorus by dairy cows fed three amounts of phosphorus. J. Dairy Sci. 83:1028-1041.

## Fecal Phosphorus Characteristics of Forage Fed Beef Cattle

**Abstract**

Phosphorus loads in waterways are a focus of environmental concern. Animal agriculture's contribution to this problem has been documented and efforts are focused on mitigating the issue. The effect of increasing amounts of mineral P supplementation on fecal P characteristics was studied in forage fed beef steers. Eight Hereford steers were fitted with total fecal collection bags and fed four diets with a low P grass hay and supplemented with increasing amounts of a mineral source of P, dicalcium phosphate. Dietary DM P concentrations were 0.10 (no P supplementation), 0.23, 0.34, and 0.45% P. Manure was sampled and dried, followed by analysis for total P and inorganic P ($P_i$). Blood was collected via jugular venipuncture following each collection period and plasma $P_i$ was quantified. Total fecal P increased linearly with increasing dietary P concentration: 6.44, 10.6, 16.1, and 18.8 g/d ($P < 0.0001$). Fecal $P_i$ increased linearly with increasing dietary P concentration: 1.58, 2.43, 2.74, and 3.84 g/d ($P = 0.0119$) Manure P solubility, however, did not increase with increasing dietary P concentration: 23.6, 22.3, 17.3, and 20.2% ($P = 0.3646$). Plasma $P_i$ increased linearly with increasing dietary P ($P = 0.0047$). ADG and G:F were not affected by increasing dietary P content. Reducing or eliminating mineral P supplementation to forage fed beef animals is possible, if forage base proves to be adequate in P. Reducing dietary P reduces fecal P excretion and the pollution potential in ecologically sensitive areas like the Chesapeake Bay watershed.

Keywords: phosphorus, beef cattle, forage

## Introduction

Phosphorus is a mineral that is important in both plant and animal growth. A very versatile element, P's most important roles are in bone formation and structure, energy metabolism and transfer of genetic information. Phosphorus is primarily contained in bone tissue (80-85%) with a smaller amount contained in fluid and soft tissue (15-20%) (Ternouth 1990). Phosphorus fed in excess of dietary requirement is excreted. In cattle fed forage-based diets, the primary route of P excretion is via feces (Ternouth, 1990).

Excess P contained in soils and waterways can contaminate surface waters through eutrophication (Sharpley et al., 2003). The Environmental Protection Agency (EPA) has identified agriculture as a significant non-point source of P runoff in the Chesapeake Bay watershed (EPA, 2010). Fecal inorganic P ($P_i$) is strongly correlated with dissolved reactive P (DRP) in soils (Kleinman, 2005). This DRP is a known cause of eutrophication (Murphy and Riley, 1962). While dairy cattle typically excrete more P than beef cattle, the number of beef animals greatly exceeds dairy in Virginia (USDA, 2010). Reducing overall P loads will likely involve reducing P output from grazing beef cattle. Studying fecal P fractions is a useful way to quantify beef's contribution to P loads in the Chesapeake Bay area.

Brokman et al. (2007) suggests that P supplementation may not be necessary for grazing stocker cattle, provided that the forage base is adequate in P content. Reducing or eliminating P supplementation reduces fecal P excretion (Barnett, 1993; Dou et al., 2003; Sharpley et al., 2003). Moreover, P is the typically the most expensive mineral to supplement, so eliminating it could be beneficial economically and environmentally (Myer et al., 2010). The objective of this study is to determine the effect of P supplementation on fecal P in forage fed beef cattle, quantifying the relationship between P intake and P excretion. Results will assist in dietary P recommendations as well as contribute to the development of a field tool to assist extension professionals and producers in assessing the P status of pastureland and grazing beef animals.

**Materials and Methods**

All procedures for this study were approved by the Virginia Tech Institutional Animal Care and Use Committee (12-033-APSC).

Eight Hereford steers (initial BW = 304 kg; SD = 22 kg) were arranged in a replicated 4 x 4 Latin Square design and fed a grass hay based diet, with four treatments of dietary P (0.10%, 0.23%, 0.34%, and 0.45% DM; Table 1). The steers originated from the same farm and were sired by one of two bulls, to minimize genetic variation. The animals were housed in individual (9.5' x 20') pens and fed separately for 8 weeks. An adaptation period of 9 days was followed by a collection period of 5 days for each period.

The cattle were fed a total of 5 kg low-P grass hay split between two daily feedings. In the evenings, they were fed a supplement that contained 0.79 kg/d beet pulp, 0.23 kg/d rumen-protected fat supplement (Energy Booster 100, Milk Specialties Global), 20 g of a P-free trace mineral salt (Champion's Choice Selenium 90, Cargill; Table 1) and varying levels of dicalcium phosphate. This supplement was covered in water and allowed to soak for approximately 30 minutes. The beet pulp mixture was fed separately, and no refusals were observed. Cattle on the LOW diet were to receive 6 g P/d (50% of requirement for 300 kg beef cattle gaining 0.5 kg/d), MED diet was formulated to be at the 12 g/d requirement, HIGH was 18 g/d (150%) and the VHIGH diet was to be 24 g/d (200%). Steers were weighed at the end of each collection period.

During the collection period, the steers were fitted with total fecal collection bags (Tolleson and Erlinger, 1989). Prior to the beginning of the study, the steers were halter broken and adapted to wearing the harnesses and bags. Bags were changed twice daily at each feeding, rinsed thoroughly, and set out to dry. Manure was weighed and collected twice daily in large barrels and sampled daily. Samples were stored at 2°C until the end of the collection period for analysis. Samples were weighed and then dried in a 60°C forced-air oven. Samples were ground through a 2 mm Wiley Mill then through a 0.2 mm Z-grinder.

Hay was sampled daily during the collection period and pooled within period. Hay refusals were weighed and subsampled daily then pooled by animal within period. DMI reported was adjusted for refusals. All hay and feed samples were stored at 2°C in a large plastic bag then weighed and dried in a 60°C forced-air oven (Precision Scientific Company, Chicago, IL) and ground through a 2 mm Wiley Mill (Arthur A. Thomas Company, Philadelphia, PA) for analysis. NDF, ADF, CP, and ash were quantified with each sample (Association of Official Analytical Chemists, 1984; Van Soest et al., 1991). A subsample was ground through a Z-grinder (Retsch ZM 100) with a 0.2 mm screen for P analysis.

Blood samples were collected by jugular venipuncture in 10-mL vacutainers containing sodium heparin after the final feeding of each period. Samples were placed on ice following collection and centrifuged on at 1,850 x *g* for 15 min at 4°C. Plasma was removed and an aliquot frozen for later analysis.

Feed offerings, refusals and fecal samples were analyzed for total P content using the perchloric acid digestion technique described by Eaton et al. (1998). Feed offerings, refusals, and fecal samples were extracted with 0.5 *M* HCl (extracted for 4 h at ambient temperature, then centrifuged at 30,000 × *g* for 10 min at 4°C) and analyzed for $P_i$ using the molybdenum blue method as described by Murphy and Riley (1962). Blood plasma was analyzed for $P_i$ using the colorimetric method described by Miles et al (2001).

Excretion and performance data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) for a Latin square design. Animal was considered a random variable, with treatment and period as main effects. Treatment differences were tested using orthogonal contrasts to test linear, quadratic, and cubic effects of P concentration.

**RESULTS AND DISCUSSION**

Average P intakes were 4.74, 11.7, 17.4, and 23.2 g/d (linear effects, $P<0.0001$) for treatments LOW, MED, HIGH, and VHIGH (Table 3), respectively. Diets were initially formulated to be a function of published NRC P requirements. Variation in individual P intake meant that targets were not precisely met, but were close (50, 100, 150, 200% formulated vs. 39.5, 97.3, 145 and 193% actual). The range of P intake levels were similar or slightly below recent beef cattle nutrition studies (Brokman et al., 2007 and Geisert et al., 2010). . No treatment x period interactions ($P>0.20$) were detected.

No dietary treatment effects were observed for DMI, ADG, or G:F. Geisert et al. (2010) demonstrated that very high P supplementation (0.31 and 0.38%) had detrimental effects on DMI and ADG. The authors attribute this to the palatability of top dressed monosodium phosphate. In the current study, the lower nutrient content of the grass hay was likely a limiting factor in animal weight gain.

Calcium concentration differed across diet, as varying levels of dicalcium phosphate were fed for each treatment. Ca:P ratios, in order of increasing P concentration, were 4.7:1, 2.6:1, 2.2:1, and 1.97:1. A Ca:P ratio of 2:1 is considered ideal for growth and bone formation as it most closely matches the mineral ratio present in bone (McDowell, 2003). Wise et al. (1963) demonstrated that dietary Ca:P ratios less than 1:1 or greater than 7:1 adversely effected performance traits. In this study, the Ca:P ratios are safely within those margins, so it is unlikely that Ca:P ratio affected DMI or ADG.

Total fecal P (Table 4) increased linearly with increase in dietary P ($P<0.0001$). Both endogenous and excess dietary P losses are included in the fecal P excretion values. Dietary management of fecal P losses has been demonstrated, particularly in dairy cattle (Dou et al., 2003; Erickson et al., 2000; Knowlton et al., 2004). As dietary P concentration increased, total fecal P increased, indicating a positive linear relationship (Figure 1). Geisert et al. (2010) noted that the intercept (2.84 g/d; Figure 1) demonstrates the amount of P excreted when no P is fed, an estimate of endogenous P excretion. Ternouth et al. (1990) concludes that plasma $P_i$ is indicative of dietary $P_i$ intake. Plasma $P_i$ was shown to increase linearly with increasing dietary P ($P<0.005$) (Table 4, Fig. 5).

Increased P supplementation had no effect on CP or fiber digestion (Table 2), which supports findings from Cohen (1972). OM digestion was not impacted by increased P supplementation ($P<0.3259$) (Table 2).

Phosphorus digestibility in this study includes endogenous P losses. Apparent P digestibility was sensitive to dietary P intake ($P<0.0065$). A negative P digestibility was calculated for steers fed the LOW P diet (4.74 g/d). This indicates that, on average, they excreted more P than they consumed, likely due to endogenous P losses. Geisert et al. (2010) did not observe depressed apparent P digestibility at greater P intakes. On the other hand, Brokman et al. (2007) and other researchers observe that apparent P digestibility decreases with increasing P intake (Challa et al, 1989; Wu et al., 2000).

Inorganic P ($P_i$) excretion was linearly related to dietary P intake ($P<0.0119$) (Table 4). Increased dietary P concentration led to more $P_i$ excreted in the feces, but manure P solubility (Table 4) was not related to dietary P concentration. Manure P solubility is calculated by dividing fecal $P_i$ excretion by total fecal P excretion (Barnett, 2003). It has been demonstrated that $P_i$ is directly related to plant yield and P uptake responses in plants and soils, causing environmental concern (Barnett, 1993; Sharpley et al., 2003). The literature suggests $P_i$ makes up a much larger proportion of total fecal P in diets of increasing P concentration, and is often affected by dietary concentration (Dou et al., 2010; Powell et al., 2007). Manure solubility has been reported to typically exceed 50% (Barnett, 1994). In an extensive review paper, Barnett (1994) reported that dairy cattle tend to have the highest concentration water-soluble P in manure, followed by feeder and feedlot cattle. A wide variety of factors impact the proportions of P excreted in manure from P intake and method of manure disposal (bedded vs. composted vs. fresh, etc.) to physiological stage of the animal and feedstuff (Barnett, 1994; Kleinman et al., 2005). Manure samples were taken from cattle in a variety of physiological stages. Both concentrate and forage based diets were included in this figure, accounting for some variation. The value of manure P solubility as a predictor of P in runoff is questioned, due to variation in total fecal P excreted (Kleinman et al., 2005). It is interesting to note that in this particular study, manure P solubility was not sensitive to dietary P concentration ($P = 0.3646$), contrary to what much of the literature suggests (Dou et al., 2002).

Spiekers et al. (1993) proposed that fecal P can be divided into three portions: unavailable dietary P that cannot be absorbed, endogenous P, and the fraction that is regulated by dietary P. Dou et al. (2002) contends that this last fraction is largely water soluble, as it reflects the portion of P that was consumed in excess of animal requirements. Differences in P availability among the ingredients used in this study were accounted for in the table. Table 5 is an adaptation of Spiekers et al. (1993). A correlation analysis revealed that $P_i$ is positively related to the regulated portion of fecal P ($r = 0.5488$).

On a producer level, it is difficult to quantify the amount of total P (TP) and $P_i$ (g/d) excreted on a daily basis, as forage fed beef cattle are not generally confined in such a way as to be able to measure total manure output. Concentration of fecal TP (% TP/g DM) and $P_i$ (ug/g DM) can be obtained from a single sample. Both of these measures are related to dietary P concentration (Fig. 3 and 4). Extension professionals in ecologically sensitive areas can use the relationship established here to mitigate P overfeeding on a producer level.

## CONCLUSION

Increasing dietary P concentration resulted in increased total P and $P_i$ found in the feces of forage fed beef steers. Plasma $P_i$ also increased with increasing dietary P. Manure P solubility was not effected by dietary P intake, even with increased P solubility in the diet. The increased dietary P showed no impact on the performance measures of weight gain, ADG, and G:F. The forage-based diet with no P supplementation was not quite adequate to meet the requirements of the growing steers. However, the mixed grass hay utilized was unusually low in P, especially for this region. It can be concluded, therefore, that a drastic reduction or elimination of mineral P supplementation for growing beef calves is feasible in typical production environment, even recommended.

## IMPLICATIONS

While it is more commonly known that beef cattle fed high concentrate diets likely need no mineral P supplementation, this study highlights the need to further scrutinize the practice in forage fed beef cattle, particularly in areas with well-managed and fertilized pastureland. Several researchers have found no detrimental long-term effects, for growth, reproductive or skeletal parameters, of reducing or eliminating mineral P supplementation, further evidence that the practice should be carefully considered when a producer has feedstuffs forages high in P. Frequent forage samples should be taken to insure that P is, in fact, adequate to meet animal needs.

**Table 1.** Composition of diets (% of diet DM)

| | Treatment[1] | | | |
|---|---|---|---|---|
| Item | LOW | MED | HIGH | VHIGH |
| Ingredient | | | | |
| Grass hay | 81.5 | 81.6 | 81.0 | 81.6 |
| Beet pulp | 14.4 | 13.9 | 13.8 | 13.1 |
| Fat supplement | 3.85 | 3.72 | 3.70 | 3.49 |
| Dicalcium phosphate | - | 0.64 | 1.25 | 1.72 |
| Trace mineral salt[2] | 0.20 | 0.19 | 0.19 | 0.18 |
| Nutrient Analysis | | | | |
| Dietary P, % | 0.10 | 0.23 | 0.34 | 0.45 |
| Dietary Ca, % | 0.44 | 0.59 | 0.75 | 0.89 |
| CP, % | 11.0 | 13.2 | 11.0 | 10.1 |
| NDF, % | 56.5 | 58.4 | 57.3 | 57.9 |
| ADF, % | 33.6 | 33.8 | 34.4 | 33.8 |
| Ash, % | 5.01 | 6.39 | 7.04 | 7.09 |
| % daily P requirement | 39.5 | 97.3 | 145 | 193 |

[1]LOW means ration contained no dicalcium phosphate. MED, HIGH, and VHIGH rations contained increasing amounts of dicalcium phosphate.
[2]Trace mineral composition: Sodium chloride, ferrous carbonate, zinc oxide, manganous oxide, sodium selenite, copper sulfate, yellow iron oxide, red iron oxide, ultramarine blue, mineral oil, calcium iodate, cobalt carbonate, and artificial flavor

**Table 2.** Diet digestibility of beef steers fed increasing concentrations of P

| Item | Digestibility, % | | | | SEM | *P*-value | |
|---|---|---|---|---|---|---|---|
| | LOW | MED | HIGH | VHIGH | | Linear | Quadratic |
| OM | 46.3 | 46.9 | 44.8 | 43.7 | 2.23 | 0.3259 | 0.6975 |
| CP | 89.5 | 84.9 | 90.0 | 87.8 | 3.91 | 0.9989 | 0.7666 |
| ADF | 41.7 | 24.6 | 34.6 | 33.4 | 6.41 | 0.5982 | 0.6406 |
| NDF | 39.6 | 37.6 | 35.0 | 36.0 | 3.16 | 0.3486 | 0.6406 |

**Table 3.** Performance of steers consuming increasing concentrations of P

| | Dietary P, % of DM | | | | | *P*-value | |
|---|---|---|---|---|---|---|---|
| Item | LOW | MED | HIGH | VHIGH | SEM | Linear | Quadratic |
| DMI, kg | 4.89 | 5.18 | 5.09 | 5.18 | 0.17 | 0.3241 | 0.5520 |
| P intake, g/d | 4.74 | 11.7 | 17.4 | 23.2 | 0.30 | <0.0001 | 0.0631 |
| ADG, kg | 0.06 | 0.27 | 0.30 | 0.24 | 0.13 | 0.3427 | 0.3294 |
| G:F | 0.01 | 0.05 | 0.06 | 0.04 | 0.02 | 0.2490 | 0.2806 |
| Ca:P ratio | 4.7:1 | 2.6:1 | 2.2:1 | 1.97:1 | 0.17 | <0.0001 | <0.0001 |

**Table 4.** Phosphorus intake and excretion in steers fed increasing concentrations of P

| | Treatment | | | | | *P*-value | |
|---|---|---|---|---|---|---|---|
| Item | LOW | MED | HIGH | VHIGH | SEM | Linear | Quadratic |
| P intake, g/d | 4.74 | 11.7 | 17.4 | 23.2 | 0.30 | <0.0001 | 0.0631 |
| P excreted, g/d | 6.44 | 10.6 | 16.1 | 18.8 | 1.31 | <0.0001 | 0.6048 |
| P digest, %[1] | -42.8 | 9.61 | 7.90 | 19.1 | 13.8 | 0.0065 | 0.1478 |
| Inorganic P excreted, g/d | 1.58 | 2.43 | 2.74 | 3.84 | 0.58 | 0.0119 | 0.8338 |
| Manure P solubility, %[2] | 23.6 | 22.3 | 17.3 | 20.2 | 3.67 | 0.3646 | 0.5662 |
| Plasma $P_i$, mg/dL | 6.40 | 8.35 | 8.72 | 9.19 | 0.40 | 0.0047 | 0.1310 |

[1]Apparent P Digestibility.

[2]Apparent Manure P Solubility = ($P_i$ excreted / P excreted) * 100.

**Table 5.** Phosphorus distribution in feces based on Spiekers et al. (1993)

| | Feces (g P/day) | | | |
|---|---|---|---|---|
| | | Undigested | | |
| Dietary P (g/day) | Involuntary endogenous[1] | Unavailable[2] | Regulated[3] | Total |
| 4.74 | 2.84 | 1.80 | 1.80 | 6.44 |
| 11.7 | 2.84 | 3.76 | 3.97 | 10.6 |
| 17.4 | 2.84 | 5.57 | 7.68 | 16.1 |
| 23.2 | 2.84 | 7.33 | 8.68 | 18.8 |

[1]Endogenous P excreted in feces. Obtained from intercept on Fig. 1.
[2]Unavailable P (g/d) = (P intake from hay x 0.34 unavailability) + (P intake from dical x 0.25 unavailability). (adapted from McDowell, 2003; Soares et al., 1995; Block et al., 2004)
[3]Regulated P determined as fecal P – unavailable P – endogenous P

**Figure 1.** Relationship between P intake and total fecal P excretion of steers fed increasing concentrations of P.

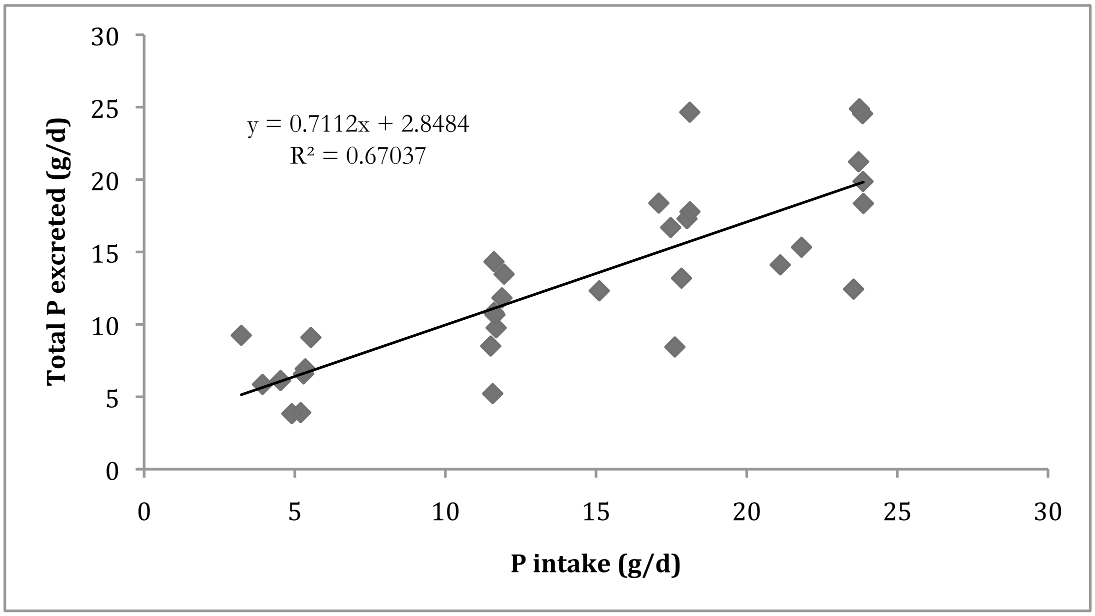



Fig. 1. Each point represents P intake and excretion by steer within period.

**Figure 2.** Relationship between P intake and fecal inorganic P excretion of steers fed increasing concentrations of P

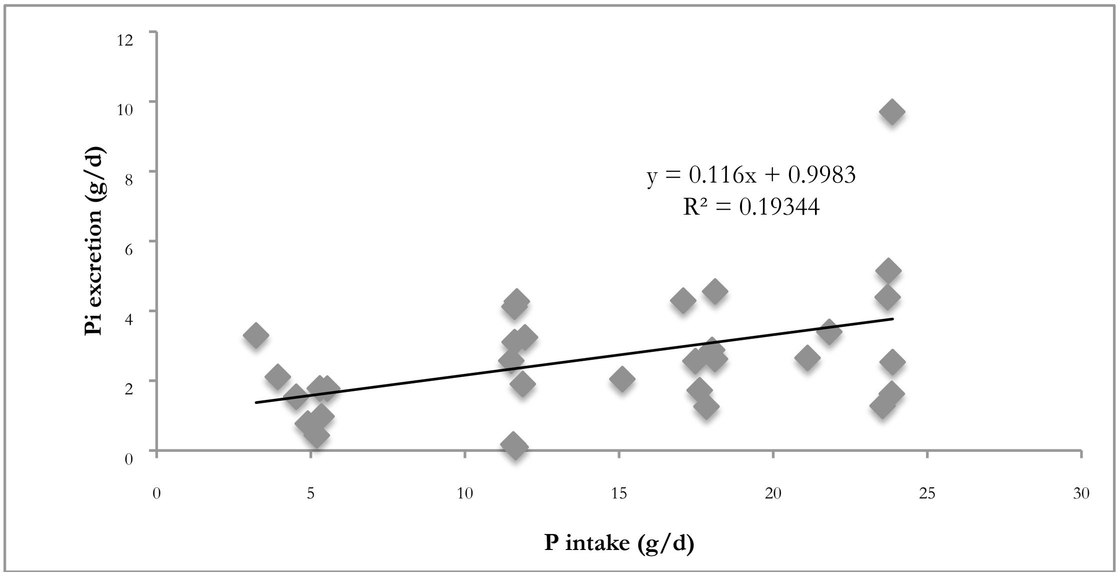


**Figure 3.** Relationship between P intake and fecal inorganic P concentration.

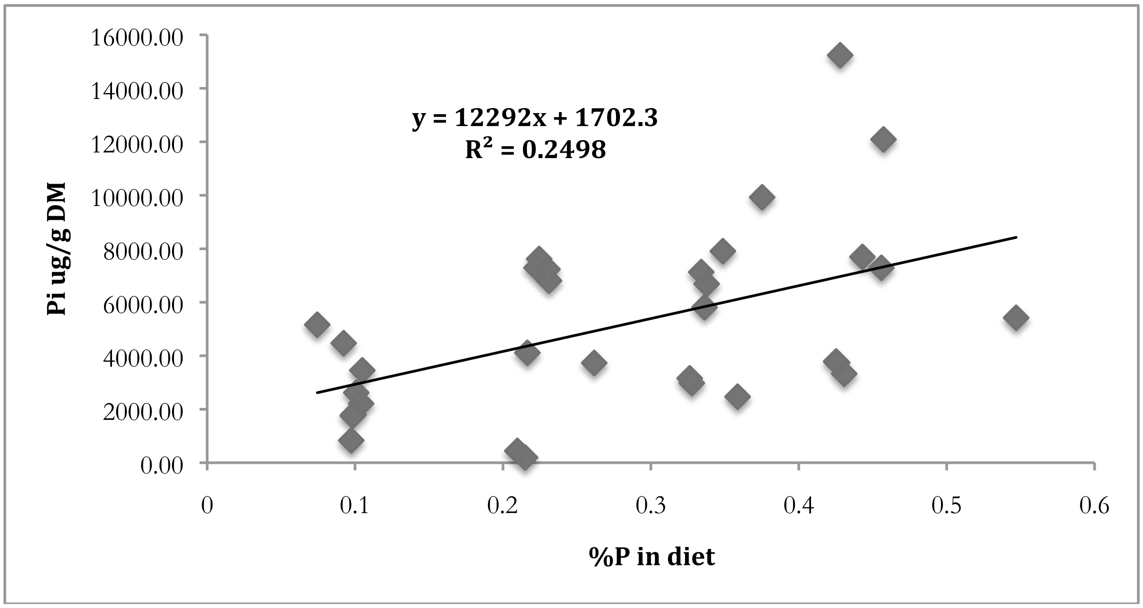


**Figure 4.** Relationship between P intake and total fecal P concentration.

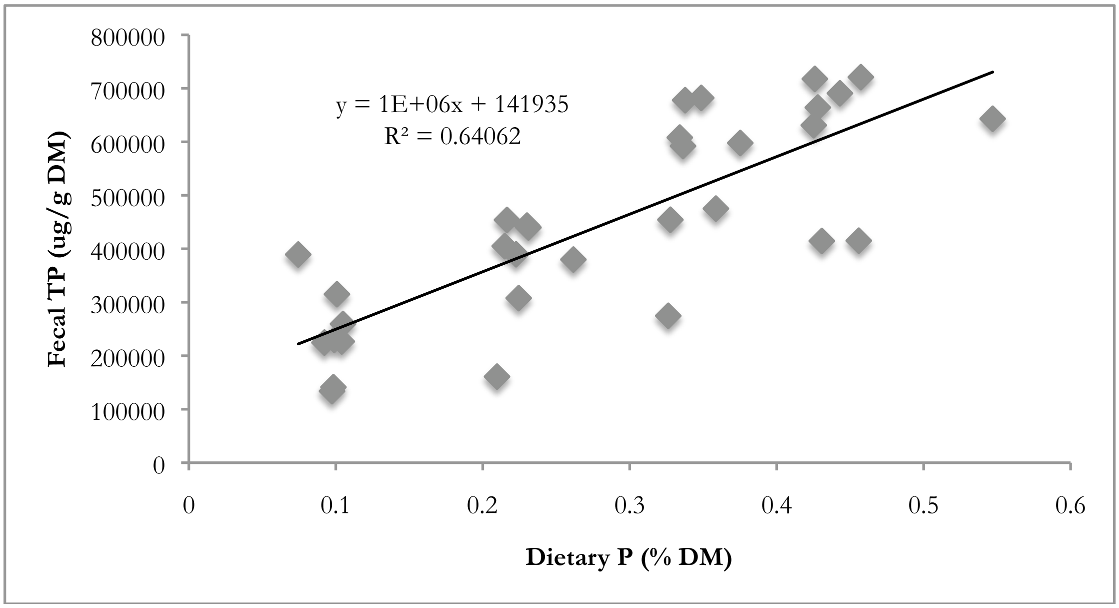
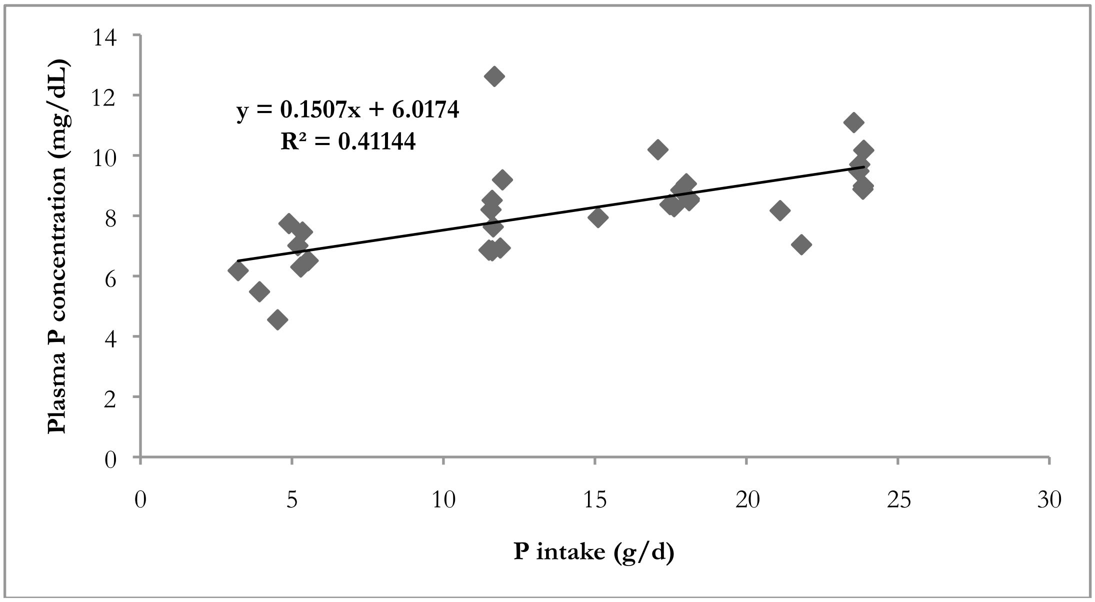


**Figure 5.** Relationship between plasma P concentration and dietary P intake.



**Literature Cited**

Barnett, G. M. 1994. Phosphorus forms in animal manure. Biores. Techno. 49:139-147.

Brokman, A. M, Lehmkuhler, J. W. and Undersander, D. J. 2008. Reducing phosphorus inputs for grazing Holstein steers. J. Anim. Sci. 86: 712-719.

Challa, J., Braithwaite, G. D. and Dhanoa, M. S. 1989. Phosphorus homeostasis in growing calves. J. Agric. Sci. 112:217-226.

Cohen, R. D. H. 1972. Phosphorus nutrition of beef cattle. 1. Effect of supplementation on liveweight of steers and digestibilty of diet. Livest. Prod. Sci, 7: 25-37.

Cohen, R. 1980. Phosphorus in rangeland ruminant nutrition: a review. Livest. Prod. Sci. 7:25-37.

Dias, R. S., Kebreab, E., Vitti, D., Portilho, F. P., Louvandini, H. and France, J. 2007. Phosphorus kinetics in lambs fed different levels of dicalcium phosphate. J. Agric. Sci.-Cambridge. 145: 509.

Dou, Z., Ferguson, J. D., Fiorini, J., Toth, J. D., Alexander, S. M., Chase, L. E., Ryan, C. M., Knowlton, K. F., Kohn, R. A. amd Peterson, A. B. 2003. Phosphorus feeding levels and critical control points on dairy farms. J. Dairy Sci. 86: 3787-3795.

Eaton, A. D., Clesceri, L. S. and Greenberg, A. E. 1998. 20th ed. Standard Methods for the Examination of Water and Wastewater. American Public Health Assoc.

EPA. 2010b. Chesapeake Bay Total Maximum Daily Load for Nitrogen, Phosphorus and Sediment. Available: http://www.epa.gov/reg3wapd/pdf/pdf_chesbay/FinalBayTMDL/CBayFinalTMDLExecSumSection1through3_final.pdf Accessed June 2012.

Erickson, G. E., Klopfenstein, T. J., Milton, T. and Walters, D. T. 2000. Dietary phosphorus effects on waste management and nutrient balance in the feedlot. Nebraska Beef Cattle Reports.

Geisert, B. G., Erickson, G. E., Klopfenstein, T. J., Macken, C. N., Luebbe, M. K. and MacDonald, J. C. 2010. Phosphorus requirement and excretion of finishing beef cattle fed different concentrations of phosphorus. J. Anim. Sci. 88:2393.

Kleinman, P. J. A., Sharpley, A. N., Saporito, L. S., Beegle, D. B. and Wolf, A. M. 2005. Survey of water-extractable phosphorus in livestock manures. Soil Sci. Soc. Amer. J. 69:701-708.

Knowlton, K. F., Radcliffe, J. S., Novak, C. L. and Emmerson, D. A. 2004. Animal management to reduce phosphorus losses to the environment. J. Anim. Sci. 82:E173-E195.

McDowell, L. R. 2003b. 2nd Ed. Minerals in Human and Animal Nutrition. Elsevier. Amsterdam, The Netherlands

Miles, P. H., Wilkinson, N. S. and McDowell, L. R. 2001. 3rd ed. Analysis of minerals for animal nutrition research. University of Florida.

Murphy, J. and Riley, J. P. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta, 27:31-36.

Myer, R., Murdock, T. and McDowell, L. R. 2010. Understanding Commercial Free-Choice Mineral Mixes for Beef Cattle. University of Florida Extension. AN245.

Odongo, N. E., McKnight, D., KoekKoek, A., Fisher, J. W., Sharpe, P., Kebreab, E., France, J. and McBride, B. W. 2007. Long-term effects of feeding diets without mineral phosphorus supplementation on the performance and phosphorus excretion in high-yielding dairy cows. Can. J. Anim. Sci. 87:639-646.

Powell, J. M, Wu, Z. and Satter, L. D. 2001. Dairy diet effects on phosphorus cycles of cropland. J. Soil Water Cons. 56:22-26.

Satter, L. D., Klopfenstein, T. J. and Erickson, G. E. 2002. The role of nutrition in reducing nutrient output from ruminants. J. Anim. Sci. 80:E143-E156.

Sharpley, A. N., Daniel, T., Sims, Lemunyon, T. Stevens, J. R., and Parry R. 2003. Agricultural phosphorus and eutrophication. USDA. ARS149.

Spiekers, H., Brintup, R., Balmelli, M., and Pfeffer, El. 1993. Influence of dry matter intake on faecal phosphorus losses in dairy cows fed rations low in phosphorus. J. Anim. Physiol. Anim. Nutr. 69:37-43.

Ternouth, J. H. 1990. Phosphorus and beef production in northern Australia. 3. Phosphorus in cattle-a review. Trop. Grassl. 24:159-169.

Tolleson, D. R. and Erlinger, L. L. 1989. An improved harness for securing fecal collection bags to grazing cattle. J. Range Manag. 42:396-399.

USDA. 2010. Virginia Annual Statistical Bulletin: Livestock and Dairy. Available: http://www.nass.usda.gov/Statistics_by_State/Virginia/Publications/Annual_Statistical_Bulletin/index.asp Accessed June 2012.

Wise, M. B., Smith, S. E. and Barnes, L. L. 1958. The phosphorus requirement of calves. J. Anim. Sci. 17:89-99.

Wu, Z., Satter, L. D. and Sojo, R. 2000. Milk production, reproductive performance, and feacal excretion of phosphorus by dairy cows fed three amounts of phosphorus. J. Dairy Sci. 83:1028-1041.