Feed What You Need: The Role of Animal Nutrition in Facilitating P-based Manure Management

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Introduction

Phosphorus (P) is a limiting nutrient in natural systems including modern crop and animal production. As such, providing both crops and animals with sufficient P to meet requirements is a hallmark of modern agricultural production systems. Phosphorus also happens to be a limiting nutrient in aquatic ecosystems and when introduced to surface water can accelerate of the process of eutrophication (aging) of a water body.

Manure application practices have been identified as a source of P entering surface water, usually as the result of runoff and soil erosion events. Research in Alberta and other jurisdictions has revealed that long-term, repeated application of manure in excess of crop P removal increases the risk of P being lost in runoff. In other words, sustainable manure management that aims to protect water quality should strive to balance manure P application and crop P removal.

In Alberta, manure application regulations are based on nitrate nitrogen (N) limits for each of the four soil zones and so application is more likely to be based on N in manure relative to crop uptake. The practice of N-based manure application, however, likely leads to the over application of manure P due to the N-to-P ratio of manure relative to the ratio in which these nutrients are taken up by crops (Table 1).

Table 1. Nutrient balances in manure relative to crop removal.

Species	Crop N: Total P in manure[1]	Crop	N:P removal by crop[2]
Hog	1.5	Wheat (40 bu/ac)	4.8 – 7.2
Dairy	2.1	Barley (80 bu/ac)	4.3 – 6.5
Poultry	1.9	Peas (50 bu/ac)	6.4 – 9.6
Beef (feedlot)	1.3	Canola (35 bu/ac)	3.5 – 5.2

[1]Source: 2000 Code of Practice for Responsible Livestock Development and Manure Management, AAFRD
[2]Source: Canadian Fertilizer Institute (Note: P converted from P_2O_5 to P basis)

Moving to a P-based application system is likely to have two main consequences for producers. First, it will require access to a much greater land base to apply manure sustainably. Second, it is likely to increase manure handling and application costs since manure will have to be transported greater distances from the storage facility and it will take longer to apply, since would likely be applied at lower rates (i.e., fewer gallons applied per hour).

Many livestock producers have limited access to the kind of acreage that P-based manure application would mandate and will therefore be forced to lower manure P output. In this respect, the producer then has two options: reduce the number of livestock on the operation or reduce P excretion per animal. Of these two options the latter is preferred since 1) it would allow the producer to maintain animal numbers and potentially expand in the future, 2) it would allow manure to be applied at a higher rate and would therefore reduce the amount of time required to apply manure, and 3) by addressing inefficiencies in the animal feeding program may reduce cost of production.
This paper will highlight some of the key issues relating to P nutrition of livestock and will look at the potential impact of specific feeding strategies designed to reduce P excretion.

Key issues in P nutrition of livestock

Before getting into a discussion of specific strategies, it might be useful to look at a couple of the major issues relating to P nutrition of livestock which will ultimately influence the amount of P excreted by livestock.

Available versus total P in feed ingredients

Phosphorus exists in plant-based feed materials in several different forms, including inorganic and organic forms. The majority of P in plant-based livestock feeds is in the form of the organic molecule phytate (Table 2), which is essentially an inositol ring bound to six phosphate molecules.

Table 2. Total, Phytate and Non-Phytate P Content of Common Non-Ruminant Feedstuffs Along with Estimated Availability for Pigs and Chickens.

Feedstuff	**Total P** (%)	**Phytate P** (% of total P)	**Phytase activity** (FTU/kg)	**Available P for pigs** (% of total P)	**Available P for chickens** (% of total P)
Barley	0.36	61	1016	31	50
Wheat	0.29	79	1637	50	38
Corn	0.23	78	70	15	33
Peas	0.43	56	86	47	---
Canola meal	1.05	72	41	21	43

Sources: Leeson & Summers (2005), Patience et al. (1995), Soares (1995), Viveros et al. (2000).

Ruminants (i.e., cattle, sheep) are able to utilize phytate P thanks to the production of the necessary enzymes (i.e., phytases) by the rumen microflora. Non-ruminant animals (e.g., pigs and poultry) on the other hand do not have significant microbial populations in the upper digestive tract and, like ruminants, they themselves do not produce the necessary enzymes to digest phytate to any appreciable extent and release the phosphorus it binds. Feedstuffs contain varying concentrations of intrinsic phytase enzyme activity which can increase the amount of total P the animal can extract from the feed beyond the non-phytate P content (i.e., some of the phytate P is being digested, Table 1). The percentage of P in a feedstuff that the animal is able to digest as a result of the combination of intrinsic phytase activity and the amount of non-phytate P is referred to as the percentage of *available* P.

Pig and poultry rations are formulated based on available rather than total phosphorus content. Any deficit in available phosphorus requirements not met by plant-based feed ingredients has traditionally been met through the use of mineral phosphate supplements such as dicalcium phosphate. The discrepancy between total and available phosphorus content of feeds has two major implications. First, the total P content of complete animal rations far exceeds the amount animal required by the animal meaning that the excess (i.e., non-available P) will be excreted in the manure. Second, inorganic P supplements are expensive relative to other feed ingredients, and as such inflate the cost of feed.

P levels in rations vs. animal requirements

When P is fed above the required level, the excess is excreted since the animal body has a very limited ability to store phosphorus in addition to what is required for physiological requirements. As such, feeding animals excess P does not make wise economic sense.

The level of P in the ration is a particular issue in ruminant nutrition, since in certain situations P is present in the basal ration in excess, even without the addition of inorganic P supplements. A prime example of this phenomenon is in beef feedlot rations with a high percentage of grain concentrate.

Ruminants require at least some forage (e.g., silage) in their ration in order to maintain rumen microbial populations, but in order to meet the high energy requirements of a growing or finishing animal, rations typically contain a high ratio of cereal grain to forage. Due to the relative P content of cereal grains and forage, this often results in rations where the P content of the base ingredients exceeds animal requirements.

If we compare a typical Alberta barley-based rations against recommended P levels (NRC, 1984 as reported in AAFRD, 1990), we find that even without any supplemental P, animals are consuming 40 to 60% more P than they actually require (Table 3).

Table 3. Estimation of P Surplus Supplied by Barley-Barley Silage, Barley-Alfalfa Silage and Barley-Corn Silage Feed Formulations for a 925-lb, Large-Framed Steer with an Average Daily Weight Gain of 3.1 lbs/d[1].

	Ration type		
	Barley/ Barley silage	**Barley/ Alfalfa silage**	**Barley/ Corn silage**
Grain-to-forage ratio, dry matter basis	56:44	59:41	89:11
P requirement, % of ration dry matter	0.23	0.23	0.23
P in ration, % of ration dry matter	0.33	0.33	0.36
Surplus P, % above requirement	43.5	43.5	56.5
Surplus P, g/d above requirement	9.8	9.8	12.7

[1]Calculations based on information from the Cattle Nutrition Home-Study Course Manual (AAFRD, 1990). Based on steers with hormone implant consuming 9.8 kg DM/d of ionophore-supplemented rations.

To further exacerbate the problem, recent research suggests that the existing requirements for phosphorus, which are in some cases based on data that are 50 years old, are much higher than what is actually required by modern feedlot cattle. Two studies suggest that the P requirement for feedlot cattle is probably closer to 0.16% of dry matter, or less (Erickson et al., 1999; Erickson et al., 2002).

Comparing these revised recommendations against the levels in the rations presented in Table 3, feedlot cattle on typical AB rations are likely supplied with between 100 and 180% more P than they actually require by the base ingredients in the ration alone.

"Safety" margins in feed formulation

It could be said that livestock nutrition and feed formulation is a game of averages. Nutritionists must take into account several potential sources of variation to develop a feed formulation that will not act as a limiting factor on animal productivity. Some of these sources of variation include:

- Published versus "true" requirements: nutrient requirements are essentially estimates derived from models based on many years of research with animals with different genetics under a variety of management conditions.
- Feed intake: in many situations, very difficult to predict under practical conditions without historical, operation-specific data.
- Nutrient content of feed ingredients: the use of "book" values and prediction equations to estimate digestible nutrient content from more easily measured parameters (e.g., digestible energy from fiber content) inherently include a level of uncertainty.

With the level of competitiveness in the feed industry for clients, it probably comes as little surprise then that nutritionists try to offset the uncertainty associated with animal feeding by building in a margin of safety into their formulations in order to provide clients with some assurance that the nutrient requirements of their animals will be met.

Strategies for reducing P excretion

Reducing the safety margin

As mentioned above, rations are routinely formulated to exceed the base requirements established through examination of research in order to account for variation between animals and management situations. The all-important question for many is how large does this margin of safety need to be? Five percent? Ten?

Limited information exists about the levels of P currently being fed to livestock in Western Canada, although some recent data reported from Manitoba suggests that P levels in dairy rations far exceed current recommendations (Table 4).

Table 4. Extent of surplus phosphorus in rations fed to lactating cows on Manitoba dairy farms (adapted from Plazier et al., 2002).

Parameter	Median	Range
P surplus, % above requirement	51.9	5.9 – 116.7
P surplus, g/d above requirement	26.5	3.0 – 56.0

If this situation is an accurate representation of what is occurring in the Alberta dairy industry or in other livestock commodities, formulating rations with P levels closer to published requirements would substantially reduce the amount of P being excreted by confined feeding operations.

Phase/group feeding

Animals require nutrients for four basic physiological functions: maintenance, growth, reproduction and lactation. Of these four functions, only the latter three have commercial value for the producer, while maintenance nutrient requirements can be regarded as the nutritional "overhead" costs associated with having a productive animal.

As might be expected, an animal's requirement for P is entirely dependent on its level of production (e.g., early lactation vs. late lactation) and as such an animal's P requirement is not a static number. Consider, for instance, the example in Figure 2, which illustrates the change in available P requirements over the 20-120 kg weight range for a growing pig.

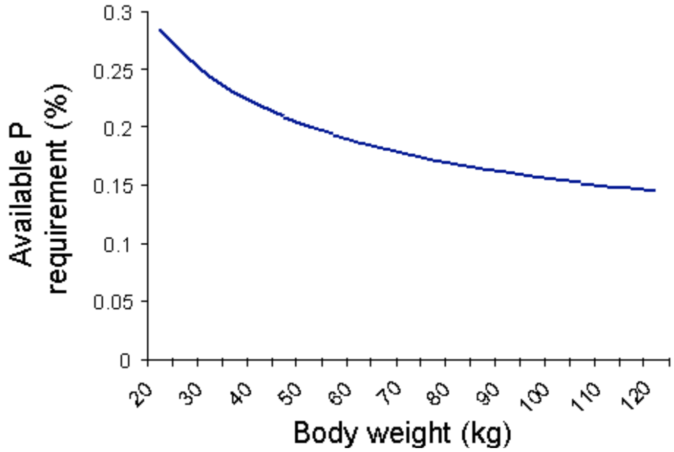

Figure 2. Available phosphorus requirement of a growing finishing pig over the 20-120 kg weight range (based on NRC 1998).

There is a gradual decline in the required percentage of available P for two reasons. First, the pig's growth rate plateaus as it get closer to market weight; and second, the pig's expected feed intake typically increases roughly three-fold over the 20-120kg weight range.

Were we to feed a single level of available P for the duration of the growth phase (Figure 3a), we run the risk of over- or undersupplying P relative to the animal's requirements depending on where we decided to set the level. Since animals do not have the ability to store P until it is required, surplus P would be excreted and during periods of deficiency productivity would likely be affected.

In a practical context, the best way to deal with this variation is to break up the production cycle into several shorter phases that reflect the most pronounced shifts in nutrient requirements, and then formulate rations specific to each (Figure 3b).

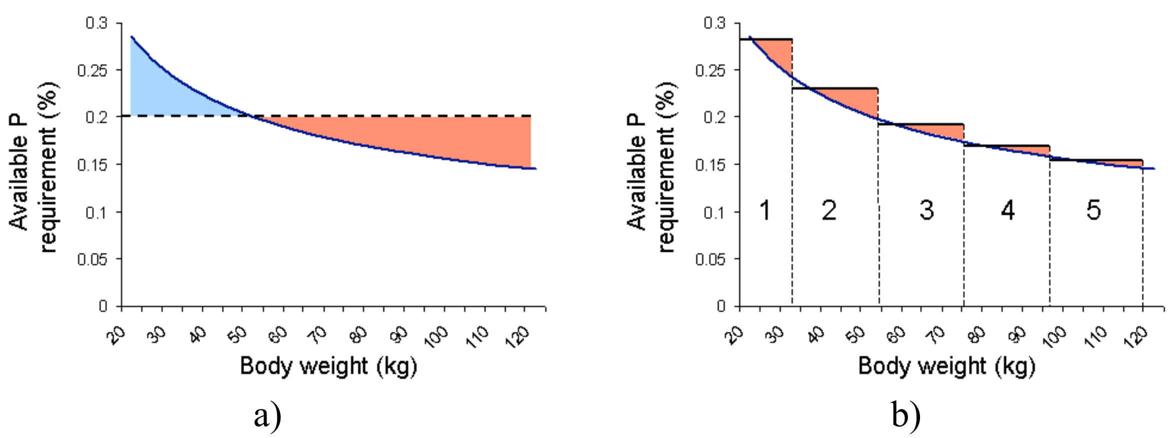

Figure 3. Graphical comparison of available P supplied versus required for a grower pig a) fed a single level of P (% of diet) over the 20-120 kg weight range compared to b) 5 levels of available P (% of diet) over the same period in a phase-feeding system. Blue-shaded areas represent deficiency, while red-shaded areas represent surplus relative to P requirements.

Based on a review of existing research, phase/group feeding of animals has the potential to reduce P excretion between 5 and 10 percent depending on the number of phases currently in use (Sutton and Lander, 2003a; 2003b; 2003c; 2003d).

Managing feed wastage

Feed wastage is the pre-eminent example of inefficiency due to the production system as opposed to a biological inefficiency (i.e., due to animal factors). Feed wastage can become a factor in manure management since in many confined feeding operations feed that is wasted often winds up in the manure, thereby contributing to the nutrient load in the manure.

In most practical situations, during passage through the animal, somewhere in the neighborhood of 20 (e.g., laying hens) to 50 percent (e.g., growing pig) of the total P in the ration is retained or exported in saleable product. The balance of intake P is excreted in the manure. When waste feed is added to the manure, its relative contribution to manure P loading is greater per unit than manure, since none of the P has the opportunity to be sequestered. Consider, for example, the situation of a growing pig over the 20-120 kg weight range (Figure 4).

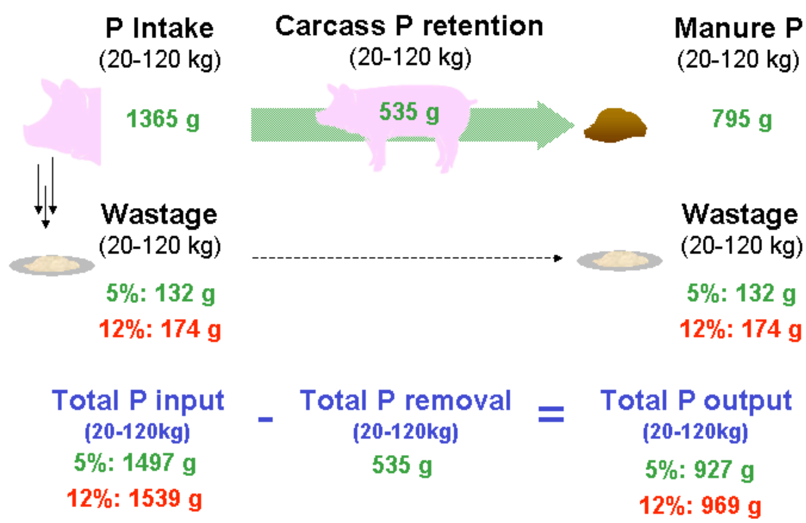

Figure 4. Hypothetical alterations in P balance from a growing-finishing pig over the 20-120 kg weight range resulting from an increase in feed wastage from 5 to 12%, based on the model proposed by Carter et al. (2003) and outputs from the NRC growth model (1998).

Based on balances estimated using the equations in Carter et al. (2003), practical Western Canadian least-cost rations formulated to meet NRC (1998) specifications with modifications based on PSCI (2000), we see that that 12% feed wastage results in a 4.5% increase in total P output relative to 5% feed wastage.

While some feed wastage is likely inevitable in confined feeding operations, steps should be taken to minimize its occurrence as it not only increases the nutrient load in the manure but also inflates production costs.

Microbial enzyme supplementation

One of the more exciting developments in non-ruminant nutrition is the development of large-scale production of microbial enzyme supplements, with microbial phytase being perhaps the most extensively studied.

Microbial phytase improves the availability of phosphorus in feed ingredients through liberating some of the phosphorus from the phytate complex. Data from both poultry and pigs have revealed that phosphorus availability increases dramatically through the use of microbial phytase supplementation (Table 5).

Table 5. Impact of phytase supplementation in a pea/barley-based diet for growing pigs (from Oryschak et al., 2002).

Parameter	Un-supplemented diets (no microbial phytase)	Diets supplemented with microbial phytase
P intake, g/d	4.02	4.04
P excretion, g/d	2.41[a]	1.74[b]
P digestibility, %	40.1[a]	57.0[b]
P retention, % of intake	40.0[a]	56.9[b]

[a,b] Different superscripts in rows indicate significant differences ($P<0.01$)

An important point with phytase is that in order to see a reduction in P excretion, inorganic P supplementation must be reduced to account for the additional P made available by the enzyme.

Future directions

There are other strategies that are currently under investigation or that have been proposed for investigation that have potential to reduce P excretion from livestock. A couple of the more promising ones are the development of low-phytate grain varieties for non-ruminants and fat supplementation for beef feedlot rations.

Low phytate grains

In order to increase the availability of P in non-ruminant feed ingredients, most nutritionists would probably agree that the best available technology at present is microbial phytase supplementation. One of the more promising developments on the horizon that may help address this issue in the future is the identification of low-phytate grain varieties, which have the same total P content as the "unimproved" strains but contain a greater proportion of the total P in non-phytate form.

Several strains of low-phytate corn and barley have been identified and show great promise for reducing the margin between total and available P in non-ruminant rations (Figure 5).

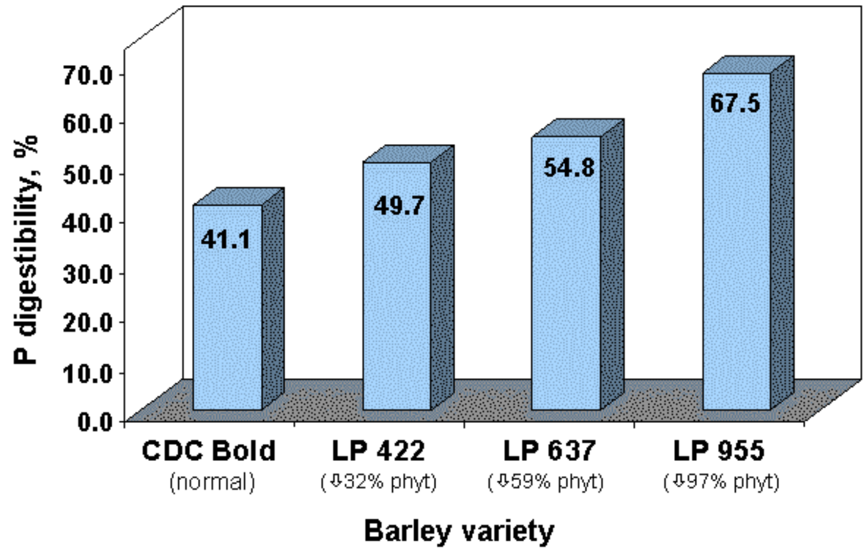

Figure 5. Phosphorus digestibility in three low-phytate varieties compared to one normal barley variety when fed to finishing pigs (adapted from Thacker et al., 2003). Note that only LP 955 had a statistically higher P digestibility than CDC Bold.

While low-phytate varieties may still have agronomic issues that must be addressed before they are market-ready and can be released to growers, this approach has huge potential to reduce P excretion through narrowing the ratio of total to available phosphorus in non-ruminant rations, particularly since grains make up in excess of 70% of most rations.

High oil diets for ruminants

High oil diets for ruminants, in particular feedlot cattle, are receiving renewed interest as they have the potential to reduce greenhouse gas emissions resulting from ruminant digestion. One of the accompanying benefits is that these diets have the potential to reduce phosphorus excretion as well.

Oils have a much higher dietary energy density than cereals and could be used to offset part of the high energy requirement of finishing animals. By doing this, we reduce the P content of the ration in two ways. First, oil contains no P, so by substituting oil for cereals we maintain energy density while reducing the level of total P in the ration. Second, because the oil offsets part of the energy requirement, the composition of the diet shifts towards a higher content of forages, which tend to be lower in P than cereals.

If we go back to the rations in Table 3 and look at what would happen if we were to include 5% vegetable oil in the ration, we see that the P surplus problem is reduced (Figure 6).

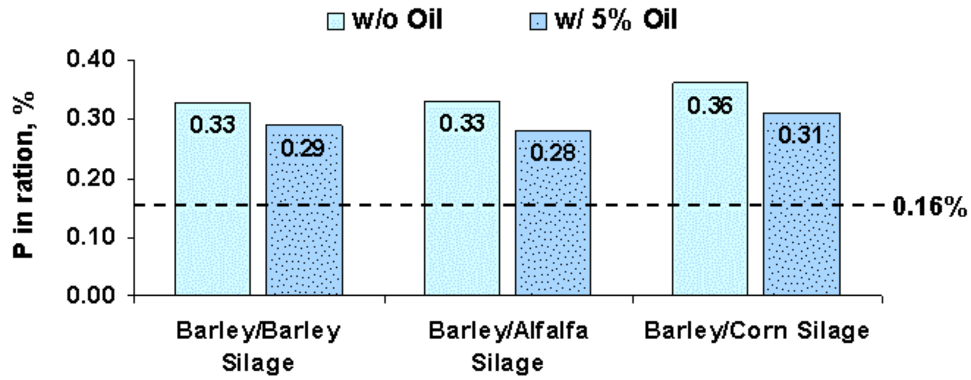

Figure 6. Effect of supplementing diets from Table 3 with 5% vegetable oil on P surpluses relative to the proposed requirement of about 0.16% by Erickson et al. (1999, 2002).

It should be pointed out that there are a couple of important limitations when it comes to feeding oil to ruminants. First, ruminants are unable to tolerate high levels of fat in the diet since it has a negative impact on rumen microbes. In the above example, oil was supplemented at 5% of dietary dry matter to illustrate the potential for this strategy to reduce P surpluses in the feed; however, more research would be required to determine maximum tolerable levels in feedlot rations under practical conditions.

Second, oil is a relatively expensive feed ingredient and oil supplementation would likely increase the cost of the ration, although under a P-based manure application system this might be offset by the economic benefit of reducing P levels in the manure which would allow higher manure application rates and reducing the acreage requirement.

Conclusion

A recent survey of dairy producers in the US Northeast and Mid-Atlantic states (Dou et al., 2003) revealed some valuable information about P feeding practices and the rationale behind some of the decisions being made at the farm level.

Of the 596 operations that responded, 72% didn't know the level of P that was currently in their lactating cow rations; however, only 3% of respondents indicated that they thought that P levels in the rations were excessive. The survey also revealed that roughly half of the farms relied on a nutritionist or veterinarian to formulate their rations and about 25% of respondents would not reduce the level of P in their rations because their current levels were those recommended by their nutritionist or consultant.

The take home message from this survey was that nutritionists have considerable influence over levels of P in rations and consequently have considerable influence over the volume of P that winds up in manure.

Notwithstanding, in order to make the transition to P-based manure management feasible for Western Canadian producers, we need to recognize that nutrition is part of the solution but should not be the sole focus. A multidisciplinary approach is required to address the variety of issues that producers will encounter by moving to a P-based application system.

Engineering expertise will be required to design precision application equipment that will permit application of manure at rates much lower than commonly seen in industry (e.g., 2000 gallons/acre versus 6000-8000 gallons/acre for liquid manure). In addition, engineered solutions may allow the capture of a portion of the large percentage of excreted N lost through volatilization.

Agronomy and soils expertise will be required to increase the efficiency of crop utilization of manure P, improve our understanding of soil P dynamics and how these are influenced by manure application, and threshold soil P limits for reducing potential environmental risks.

References

Carter, S.D., G.L. Cromwell, P.W. Westerman, J.S. Park and L.A. Pettey. 2003. Prediction of nitrogen, phosphorus and dry matter excretion of swine based on diet chemical composition, feed intake and nutrient retention. Pages 285-295 in Proceedings of the Ninth International Animal, Agricultural and Food Processing Wastes Symposium. October 12-15, 2003, Research Triangle Park, NC, USA. ASAE Publication 701P1203.

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

Erickson, G.E., T.J. Klopfenstein, C.T. Milton, D. Brink, M.W. Orth and K.M. Whittet. 2002. Phosphorus requirement of finishing feedlot calves. J. Anim. Sci. 80: 1690-1695.

Erickson, G.E., T.J. Klopfenstein, C.T. Milton, D. Hanson and C. Calkins. 1999. Effect of dietary phosphorus on finishing steer performance, bone status and carcass maturity. J. Anim. Sci. 77: 2832-2836.

Leeson, S.D. and J.D. Summers. 2005. Commercial Poultry Nutrition (3rd Ed.). University Books, Guelph, ON, Canada. 398 pages.

National Research Council. 1998. Nutrient Requirements of Swine (10th Ed). National Academy Press. Washington, DC, USA. 189 pages.

Oryschak, M.A., P.H. Simmins, R.T. Zijlstra. 2002. Effect of dietary particle size and carbohydrase and/or phytase supplementation on nitrogen and phosphorus excretion of grower pigs. Can. J. Anim. Sci. 82: 533-540.

Patience, J.F., P.A. Thacker and C.F.M. de Lange. 1995. Swine Nutrition Guide (2nd Ed). Prairie Swine Centre Inc. Saskatoon, SK, Canada. 271 pages.

Plaizier, J. C., Garner, T., Droppo, T. and Whiting, T. 2004. Nutritional practices on Manitoba dairy farms. Can. J. Anim. Sci. 84: 501–509.

Prairie Swine Centre Inc. 2000. Pork Production Reference Guide (1st Ed). Prairie Swine Centre Inc. Saskatoon, SK, Canada. 51 pages.

Soares, J.H. 1995. Phosphorus bioavailability. Pages 257-294 *in* Bioavailability of Nutrients for Animals: Amino Acids, Minerals and Vitamins. Ammerman, C.B., D.H. Baker and A.J. Lewis (Eds). Academic Press. San Diego, CA, USA.

Sutton, A. and C.H. Lander. 2003a. Nutrient management technical note #2: Feed and animal management for beef cattle (factsheet). United States Department of Agriculture – Natural Resources Conservation Service.

Sutton, A. and C.H. Lander. 2003b. Nutrient management technical note #3: Feed and animal management for swine (growing and finishing pigs) (factsheet). United States Department of Agriculture – Natural Resources Conservation Service.

Sutton, A. and C.H. Lander. 2003c. Nutrient management technical note #4: Feed and animal management for poultry (factsheet). United States Department of Agriculture – Natural Resources Conservation Service.

Sutton, A. and C.H. Lander. 2003d. Nutrient management technical note #5: Feed and animal management for dairy cattle (factsheet). United States Department of Agriculture – Natural Resources Conservation Service.

Thacker, P.A., B.G. Rossnagel and V. Raboy. 2003. Phosphorus digestibility in low-phytate barley fed to finishing pigs. Can. J. Anim. Sci. 83: 101-104.

Viveros, A., C. Centeno, A. Brenes, R. Canales and A. Lozano. 2000. Phytase and acid phosphatase activities in plant feedstuffs. J Agric. Food Chem. 48: 4009-4013.

Alberta Agriculture. 1990. Cattle Nutrition Course. Beef Cattle and Sheep Branch and Home Study Program, Alberta Agriculture. Edmonton, AB, Canada.