Economic Implications of Reducing Dietary Phosphorus in Dairy Rations - Ontario Canada

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Abstract:

With the recent introduction of Ontario's Nutrient Management and Clean Water Acts, on-farm environmental management has received increased attention. Phosphorous (P), being an abundant nutrient in animal manure and applied to cropland to increase yields, causes environmental concern when surplus levels runoff and enter surface water. This study focuses on the effects that reduced dietary P levels in dairy rations have on the ration costs, feed types required to reduce P to these levels, subsequent manure P content and its influence on environmental costs. Previous studies have found that reducing formerly accepted dietary P levels by 20-25% has little impact on physical aspects of the cow. Working with the dairy feed industry, rations were reformulated at P levels considered high, medium and low relative to this level of potential reduction. By using a computer calculation model, the tangible on-farm and intangible environmental savings due to P reduction in rations were calculated. A $0.08 Cdn savings per cow per day ($29 per cow per year) was found to be possible as a result of dietary P reduction from 0.503 to 0.359 P D.M. basis. Given conditions in Ontario Canada, this $0.08 savings converted to $40 per hectare per year tangible savings, and this will certainly almost always accrue. When soil P is in surplus another $40 per hectare is saved as an intangible environmental savings. When soil P is not in surplus, no environmental savings accrue and even some tangible savings are reduced because chemical fertilizers are needed. Non-surplus P scenarios had a total savings of only $32.80 per hectare as compared to a surplus P scenario of $80 per hectare. The field tests recorded that dietary P level was reduced by 28.57% between the high P diets at 0.503% and the low P diets at 0.359%; a significant reduction.

Statement on Animal Care:

This project did not involve the direct use of animals. Only records of animals were used. The respective animals were owned and housed on private farms, and to the best of my knowledge were treated humanely and in accordance with best management practices and the voluntary code of practice within the industry.

(dairy cattle, phosphorus, environment, economics)

The Problem:

For years, dairy rations have been formulated assuming P levels at 0.5% DM (NRC, 1989). This has been challenged of late, and NRC (2001) has lowered their P requirements in dairy diets. Valk (among others, Wu and Satter 2001) estimates from feed trials that 0.31% P DM seems to be about borderline deficient for lactating dairy cattle. Given the potential savings in feed mineral costs and assuming no adverse effect on animal production or health, will this translate into real business savings and environmental savings?

Objectives:

Objective (a): With the help of the animal feed industry in Ontario, calculate and analyze actual ration formulations for their farm clients. In addition to the actual ration formulation provided to the farm client, the ration would be reformulated with P levels of 0.5% (high), 0.45% (medium) and 0.34% (low), or lower.

Objective (b): The costs of each ration at various levels of P are calculated. Of particular importance are the effects on cost due to reduced mineral supplementation.

Objective (c): A review of the ration make-up would look at the types of feeds used to make up the ration. Of particular interest are the types of feeds forced into use as P levels begin to limit the use of higher P feeds. For example, corn is low in P whereas hay-crops and small grains are high in P. Objective (d): A Zero-Excess-Phosphorus (ZEP) farm calculator determined the ration cost savings (tangible) and the environmental savings (intangible) of reduced P in feeds.

Literature Review:

Pollution of water with P generally occurs because manure is applied in excess to soil. Nitrogen is reported to affect mostly air quality while phosphorus affects mostly water quality. Algal blooms in water are an indication of P as a source of pollution. Excess P in dairy diets is excreted in feces in a water soluble form. A measure of the inorganic P in a water extract is highly responsive to changes in diet P concentrations and can be indicative of dietary P status (Dou et al. 2002). The amount of P in soil is a balance of that being added and that being removed. Zero-Excess-Phosphorus (Alocilja E.C. 1998) is a concept that when used as a management tool, will balance P at the farm level. Alocilja applied ZEP within a whole-farm model including milk, livestock sales, dead stock, crops and feed.

Cash-crops will effectively export P out of the system, thus lowering P concentration in the soil. Feed-crops on the other hand, re-circulate P through the animal, back to the soil, and will therefore affect soil P levels.

The level of P as a pollutant will depend on the manure (its rate of application and the P content), chemical P fertilizer, and the crop grown on the soil. An environmental savings and an economic benefit will accrue only when soil P is in excess of plant requirements. When soil P levels are in excess and dietary P is lowered, then chemical fertilizer is not used to make up for the lower P in soil and so an intangible environmental savings will accrue. Conversely, when soil P is in deficit of optimal plant growth after dietary P reductions, then chemical fertilizer is required to make up for the reduction of P and so no intangible environmental savings are accrued and at least part of the tangible savings are negated.

Several researchers have estimated the value of P reductions in dairy rations. A reduction in dietary P to more closely match the cow's requirement can result in 25 to 30% less fecal P and a savings of $11-15 US ($15-20 Cdn) per cow per year in P supplementation costs (Wu et al., 2000). In another project in the U.S. by Rotz et al. (2002), it was found that when supplemental phosphorus was reduced to NRC requirements, a savings accrued of $22 US (about $29 Cdn) per cow per year. Stokes and Tozer (2002) approached phosphorus loading in association with nitrogen in manure and found that with a slight reduction in nitrogen (1%), and a significant reduction in phosphorus (14%), the feed cost actually went up about 1%. Satter and Wu (1999) estimate a savings of $12-15 US ($16-21 Cdn) by removing all supplemental P from dairy diets.

Methodology:

The livestock feed industry works very closely with dairy farmers in Ontario by providing them with ration formulation services. Farmers test their feeds, value them at market value and rations are formulated for cattle groups at each farm. This provides an excellent opportunity to measure the savings of P reduction and the associated environmental benefits. This close association of ration formulation by the feed industry and on-farm practice approximates a survey approach more so than a model forecasting approach commonly used by other researchers.

Two benefits can accrue due to reducing dietary P; tangible savings in mineral costs can accrue and reductions in environmental P can occur, an intangible saving. A value can be placed on the environmental P reductions if we assume the environmental benefit can only be equal to the monetary value due to ration formulation.

The on-farm measure of these benefits is unique to each farm situation because of the multitude of soil type combinations, ration requirements, production levels and values put on feed crops. However, in actuality there are only three situations that can happen; soil is in deficit before and after dietary P reduction, soil P is in excess before and after dietary P reduction, or soil is in excess before and deficit after dietary P reduction. The field data is used to calculate the net benefits of reducing dietary P in dairy rations for these three scenarios.

Description of the model:

The model in Figure 1 will calculate a ZEP system for soil. P can enter soil from manure and chemical fertilizer, and will exit soil in plants or as runoff. Starting at the top left corner of the model each line is detailed by row number:

1. Soil P content – the field has soil that measures at 55 kg p per ha. (about 84 ppm/ha P).
2. Soil Runoff - assumed to be zero within the soil ZEP cycle.
3. Manure P content – assumes 9 kg (DM) P dairy manure per tonne at 8.5% DM.
4 Manure Application Rate – assumes 3 tonnes of dry matter manure per ha. at 8.5% DM.
4.a The application rate dry matter will convert to wet manure assuming 8.5% DM, in this case 35,294 litres of wet manure per ha.

This model has five potential crops, common to Ontario Canada giving the following detail:

5. Yield in tonnes per hectare, dry matter basis.
6. Price per tonne on a dry matter basis.
7. Typical P removal rate from soil, in kilograms, per tonne of feed on a dry matter basis.
8. Number of hectares, set as one.

9. Crop value per hectare. The corn based crops were expected to be approximately the same value on a dry matter basis per hectare, and similarly the hay based crops.
10. The dry matter percent of each crop.

The lower portion of the model calculates the P balance, dollar value of P reduction in rations and the dollar value of P reduction within the environment, as such:

11. Line 11 calculates the P balance within the soil, excluding chemical fertilizer. In this case the soil for corn silage began with 55 kg P per hectare, added the P from manure (3 tonnes of dry matter manure x 9 kg per tonne of dry matter manure), removed the P from the corn silage (1 hectare x 10.5 kg P per dry matter tonne of silage x 9.8 tonnes of dry matter silage per hectare), and removed the runoff expected per hectare (set at zero).
12. Line 12 calculates the P balance within the soil, again excluding chemical fertilizer; however this is a result of the P reduced cow rations. This is the same formulation as above except that the P from manure is reduced by 3.46 kg per tonne of dry matter manure (as seen on line 14).
13. The value of P found in chemical fertilizers was found locally to be $0.69 per kg DM basis.
14. Our data found that the reduction of P in manure due to low P diets in dairy cattle was 3.46 kg per tonne of dry matter manure (data showed a 38.41% drop in manure P x 9 kg per tonne in our normal manure).
15. The data collected showed a $0.08 savings per day per cow by reducing the P in dairy rations.
    - Conversion of this value to a unit of tonnes of dry matter manure assumed a cow to produce 6 kg of dry matter manure per day (8.5% DM) i.e. ($.08 x 1000/ 6).
16. The value of P reduction in feeds per hectare is the per tonne value times the application rate per hectare ($13.33 per tonne * 3 tonnes per hectare)

17. The value of reduced P to the environment involves three scenarios, all with the overall assumption that the intangible environmental benefits cannot outweigh the tangible on-

farm business benefits. This will provide a dollar value per kg of P from an environmental viewpoint.

- Scenario 1 is a surplus situation where ‘optimal crop P requirement’ is less than both the ‘soil P balance’ before P reduction in the diets, and after. Corn is a good example in this case. (The optimal P requirements are stated in the last row).
- If soil P is in a surplus situation, then reducing P is beneficial to the environment and so will have value. The maximum benefit to the environment can be only as much as the tangible on-farm business benefits, in this case $40 per hectare.
- Scenario 2 is a deficit situation where ‘optimal crop P requirement’ is greater than both the ‘soil P balance’ before P reduction in the diets, and after. Corn silage is a good example.
- As P in the soil is in deficit before reduction, then dietary P reduction is replaced with chemical fertilizer, and no environmental benefit accrues. In fact, some of the tangible benefits are offset by the cost of additional fertilizer.
- Scenario 3 is where ‘optimal crop P requirement’ is more than soil P balance after reduction and less than soil P balance before. This is the case in this example with dry hay.
- As P in the soil is in deficit with P reduced diets but not normal diets, then some, but not all, of the P reduction needs to be supplemented with chemical fertilizers. Some extra fertilizer is required and only some environmental benefits will accrue.

18. As dietary P is reduced, and soil P is in deficit for optimal plant growth, then the amount of P required would be the optimal less the balance (as with corn silage, 0 kg/ha less -21, so requiring 21 kg). Otherwise zero (as with high moisture corn, no chemical P is required).
19. The same scenario is applied after the dietary reduction of P (again as with corn silage, 0 kg/ha less -31.4, requiring 31.4 kg).
20. The value of chemical fertilizer between the normal diets and the reduced P diets is the difference between the last two rows times the value of commercial fertilizer (for corn

silage, 31.4 less 21 all times * $0.69 per kg = $7.20). Notice the value of dietary P is $3.85 / kg ($13.33 / 3.46 kg) which is more expensive than chemical fertilizer P noted at $0.69 per kg.

21. The net benefit of reducing dietary P is culminated by adding the on-farm benefit to the environmental benefit less the cost in extra chemical fertilizer P (for hay $13.33 * 3 +$34.71 – $0.95 = $73.76).
22. The final row of the model is the P requirement kg per hectare for optimal crop growth.

Results and Discussion:

The direct economic implication of adjusting dairy rations in Ontario for high P levels was found to be $0.08 Cdn per cow per day ($29.20 per cow per year, agreeing with Rotz (2002)) (Table 1). This is a reasonable reward for the limited amount of effort it takes. Assuming no adverse effect on animal health or performance, this translates to $2,920 per year for a 100-cow herd (or $40 per hectare assuming 35,500 litres of liquid manure applied with 8.5% solids). This savings of $0.08 per cow per day is associated with a dietary P reduction from 0.503 to 0.359 percent P DM basis.

From the data, hay-based diets were associated with manure at about 60 grams P per day DM, whereas corn-based diets were associated with manure at about 68 grams P per day DM, which agrees with Morse (1992). Also, low P diets produced 38.41% less faecal P than high P diets (Table 1).

One of the concerns with low P diets was how this would affect the makeup of a ration. Within our limits, the ration changed only very slightly. As seen in Table 1 when reducing dietary P, corn silage (CS), high moisture corn, haylage and hay all were used only slightly more. This was typically at about a half percentage point. Also, less corn was used when reducing dietary P. Dietary P of 0.359 percent was as low as could be accomplished without drastically changing the forage base.

And finally in Table 1, the dietary P level was reduced by 28.57% between the high P diets at 0.503% and the low P diets at 0.359%; a significant reduction.

The results of the three scenarios can be seen by reviewing corn silage (a deficit scenario), high moisture corn (a surplus scenario), and hay (an in-between scenario). CS had a benefit of $40 per hectare due to low P diets. This is a scenario where there is not enough soil P to support proper plant growth and chemical P is required. The chemical P used to offset the dietary reduction will cost $7.20 and soil P is not reduced at all, so no environmental benefits accrue. Total benefits amount to $32.80 per hectare.

HMC also had a benefit of $40 per hectare due to low P diets. This is a scenario where there is surplus soil P for proper plant growth and no chemical P is required. No chemical P cost is accrued and soil P is reduced, so a full environmental benefit of $40 is accrued. The total per hectare benefit is $80.

Hay is an in-between scenario where with normal diets, soil P is in surplus, and with P reduced diets, soil P is in deficit, so only part of the environmental benefits are realized. Again, the benefit per hectare due to low P diets is $40. The chemical P used to offset some of the dietary reduction will cost $0.95 and soil P is only partially reduced. The environmental benefit is $34.71 for a total savings of $73.76 per hectare.

The benefits due to feed formulation will always certainly accrue. The extent to which this is eroded away will depend on two things: the price of chemical fertilizer P and the P balance within the soil. Only when soil P is in surplus will this benefit not erode. And only when soil P is in surplus will environmental benefits accrue. Soil P levels have the largest effect on this. The value of savings from P reduced diets will directly affect the benefit values per hectare. Crop yields and manure P content will have some effect on the analysis. And manure application rates will directly affect the analysis. All these are helping to create a surplus or a deficit situation.

Of particular interest to the analysis is what will not influence economic and environmental benefits from P reductions. The choice of crop in the long terms is expected to have limited effect on the analysis. When crops are sold off the farm, P is exported and this will tend to lower soil P but only when manure is not applied. When crops are used for home-grown feed, the levels of P in the feed will be reflected in the level of P in the manure. On any particular piece of land, crops requiring a lot of P might reduce soil P but when that manure is reapplied and a full crop rotation is considered, then the effect of crop choice over time will have very limited effect on soil P.

The application rate per hectare of manure will directly affect the total benefit value in two ways. Firstly, the value per tonne of manure remains the same at $13.33 but if more is applied, then the value per hectare becomes proportionally more. And as the application rate is increased, the scenario shifts to create a more surplus scenario. Again, environmental benefits only accrue under surplus scenarios.

Conclusions:

Reducing dietary P in dairy cattle will have positive on-farm economic returns. Some of these benefits will be eroded if chemical fertilizer is required to replace some of this P for optimal plant growth. Only when soil P is in surplus to optimal plant growth will environmental benefits accrue to P reductions.

Soil needs to be managed such that P is in balance with plant growth. Soils in Ontario are often reported to be surplus in P and if so, reductions in manure P will have a direct impact on the environment and reap environmental benefits.

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Figure 1: Calculator showing Net Benefit from Reduced P in Dairy Rations

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			CROPS						
			Corn Silage	High Moisture Corn	Haylage	Dry Hay	Corn		
1	Soil P Content, kg per ha	55.0							
2	Soil Runoff, assumed zero	0.0							
3	Manure P Content, Kg per T DM	9.00							
4	Manure Application Rate, DM T per	3							
4a.	Litres of wet manure per ha @8.5% D	35,294							
5	Yield T /ha		9.8	5.5	4.0	3.7	5.6	DM	
6	Price /T		$80	$139	$85	$84	$141	DM	
7	P Removal, Kg per		10.5	12.3	18.3	19.8	12.1	DM	
8	Number of ha		1.0	1.0	1.0	1.0	1.0		
9	Crop Value per ha		784	770	340	311	792		
10	Percent dry matter		35%	72%	47%	84%	85%	DM%	
11	Soil P balance, kg per ha (excluding chemical P)		-21.0	14.0	9.0	9.0	14.0		
12	Soil P balance after reduction, kg per ha		-31.4	3.6	-1.4	-1.4	3.6		
13	Value of commercia P, $/kg		$0.69	$0.69	$0.69	$0.69	$0.69	DM	
14	Reduction of P in Manure, kg / T DM		3.46	3.46	3.46	3.46	3.46	DM	
15	$ Value of P reduction in feeds per d	0.08 ....per tonne manure DM	$13.33	$13.33	$13.33	$13.33	$13.33	DM	
16	$ Value of P reduction in feeds per ha		$40.00	$40.00	$40.00	$40.00	$40.00		
17	Value of exess P to the environment, per ha		$0.00	$40.00	$34.71	$34.71	$40.00	Max	$40.00
18	Amount of chemical fertilizer P required before reductions, kg per ha		21.0	0.0	0.0	0.0	0.0		
19	Amount of chemical fertizer P required after reductions, kg per ha		31.4	0.0	1.4	1.4	0.0		
20	Cost of commercial P due to the reduction, kg per ha		$7.20	$0.00	$0.95	$0.95	$0.00		
21	Net Benefit of reducing P in dairy diets. Ration benefits + environmental benefit - che		$32.80	$80.00	$73.76	$73.76	$80.00		
22	Optimal crop P requirement, kg per ha		0	0	0	0	0		

Table 1: On-Farm Dietary Results

	Average	Numeric Difference	Percentage Difference
Cost (per head per day)			
Low	$3.75		
Medium	$3.78		
High	$3.83	$0.08	1.97%
Manure (grams per day DM)			
Low	39.04		
Medium	50.44		
High	63.38	24.34	38.41%
Corn Silage (As-fed)			
Low	13.81		
Medium	13.82		
High	13.74	-0.07	-0.50%
HMC (As-fed kg)			
Low	5.95		
Medium	5.94		
High	5.93	-0.02	-0.35%
Haylage (As-fed)			
Low	9.98		
Medium	9.96		
High	9.91	-0.07	-0.67%
Corn (As-fed)			
Low	1.62		
Medium	1.62		
High	1.63	0.01	0.44%
Hay (As-fed)			
Low	2.89		
Medium	2.89		
High	2.88	-0.02	-0.60%
P level			
Low	0.359%		
Medium	0.422%		
High	0.503%	0.144%	28.57%
Milk Yield (kg/day)	35.66		