Reducing Phosphorus Levels in Dairy Cow Diets

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Take Home Messages

- World reserves of phosphate rock are finite. We must maximize the efficiency of use of this un-substitutable nutrient.
- Phosphorus (P) losses from agricultural systems, including dairy systems, are a major cause of water pollution in many countries.
- Fertilizer and feed represent the main inputs of phosphorus to dairy farms.
- Cows are often fed more phosphorus than they actually require, and as such, there is interest in reducing phosphorus levels in dairy cow diets. However, feeding less phosphorus to dairy cows will be unacceptable if cow performance, health, fertility and welfare are compromised.
- There is now a significant body of scientific evidence indicating that phosphorus levels in dairy cow diets can be reduced to between 3.6 and 3.8 g/kg DM without having an adverse effect on cow performance.
- While cows that are deficient in phosphorus will have poor fertility, there is no evidence that fertility will be reduced by offering diets containing between 3.6 – 3.8 g phosphorus/kg DM.
- Reducing phosphorus levels in dairy cows diets will reduce the solubility of phosphorus excreted in feces, and as such, the likelihood of it being lost in surface runoff.
- Offering lower phosphorus diets can make a significant contribution to reducing the phosphorus balance of a dairy farm.

WCDS Advances in Dairy Technology (2014) Volume 26: 209 - 220

Introduction

Phosphorus (P) is an essential nutrient for all plant and animal life. Agricultural phosphorus is obtained from phosphate rock, with China, the USA, Morocco and the Russian Federation currently the world's main producers. However, world reserves of phosphate rock are finite, and at the present rate of use known reserves have a predicted lifespan of approximately 200 years (Richards and Dawson, 2008). Thus, there is an increasing need to maximize the efficiency of use of this un-substitutable nutrient, and to minimize losses from agricultural systems.

However, in many agricultural regions, and at an individual farm level, there is often a significant imbalance between phosphorus inputs and phosphorus outputs. This is particularly true on dairy farms, where the two main inputs of phosphorus are in inorganic fertilizers and concentrate feedstuffs. With regard to the latter, cows do not utilize dietary phosphorus very efficiently, and up to 70% of phosphorus consumed by cows can end up in manure. If there is heavy rain after manure is applied, phosphorus within the slurry can be washed into waterways in 'surface runoff'. Phosphorus from chemical fertilizers can also be washed into waterways. In addition, many agricultural soils contain high levels of phosphorus, especially in the upper few centimetres. When grazing animals or machinery damage the surface of the soil, soil particles containing phosphorus can be washed into rivers and lakes.

In addition to representing a loss of valuable nutrients from agricultural systems, phosphates can cause the eutrophication of waterways. Eutrophication can be defined as the enrichment of water by nutrients, especially compounds of nitrogen and phosphorus, whereby a body of water changes from a nutrient poor (oligotrophic) to a nutrient rich (eutrophic) state. Eutrophication has a number of adverse effects on water quality, including health risks associated with toxic algae and algal scums in drinking water supplies and recreational waters, damage to habitats leading to loss of species diversity, loss of fisheries, and undesirable aesthetic impacts such as odours, loss of transparency, and clogging by weeds, the latter reducing amenity value. Phosphorus is often the 'limiting nutrient' within these processes. In many parts of the world dairy farming is a significant driver of phosphorus induced eutrophication.

However, as pressure on water resources continues to grow, all agricultural sectors, dairying included, will be forced to tackle this problem with increasing rigour. Within the European Union (EU) legislation designed to improve water quality is already in place. For example, where it can be related to agricultural activities, action to control nutrient enrichment is required under the EU Nitrates Directive**.**

Two main approaches are normally advocated to reduce phosphorus losses. The first involves reducing the amount of phosphorus brought onto the farm (in fertilizer and feeds), while the second involves improving the management of manure and fertilizers, and reducing damage to the soil surface. With regard to the former, this may involve reducing stocking rates, utilizing more home-produced concentrate feeds, feeding less concentrates/cow, or feeding diets with lower phosphorus levels.

■ Feeding Diets with Lower Phosphorus Levels?

Phosphorus has many functions within a dairy cow, including maintaining bone strength (80% of phosphorus is found in bones), maintaining rumen pH, as a part of cell walls, and in all body processes that require energy. Dairy cows also secrete large quantities of phosphorus in milk each day. Rumen bacteria also require phosphorus to function properly. There is also a belief that feeding more phosphorus will improve cow fertility. For these reasons cows are often fed more phosphorus than they actually require, although it is also true that the precise phosphorus requirements of dairy cows are not well defined. Consequently, there is considerable interest in reducing the phosphorus content of dairy cow diets. However, feeding less phosphorus to dairy cows will be unacceptable if cow performance, health, fertility and welfare are compromised.

During the last few decades a number of studies have examined the effect of dietary phosphorus level on dairy cow performance, with key details of some of these studies summarized by Ferris (2009). However, many of these studies were of a relatively short term nature (less than two years), which is of concern as cows have the ability to deplete phosphorus reserves for milk production over a number of lactations, thus deficiency symptoms may not arise in the short term.

■ AFBI Research Examining 'Low Phosphorus Diets'

To address some of the shortcomings of previous research studies, the experiment described below was undertaken at the Agri-Food and Biosciences Institute (AFBI) in Northern Ireland. This study was designed to examine the effect of reducing phosphorus levels in dairy cow diets over a four-year period, with full details having been presented by Ferris et al. (2010a and 2010b).

The experiment started with 100 first lactation Holstein-Friesian heifers. A total of 95, 70, 50 and 22 cows completed each of lactations 1-4, respectively. During the winter cows were offered grass silage, maize silage and concentrates (10-12 kg concentrate/cow/day), while during the summer most cows grazed and were offered 3-4 kg concentrate/cow/day.

The diets offered contained either 'normal' or 'reduced' levels of phosphorus (Table 1). These different phosphorus levels were obtained by modifying the level of phosphorus in the concentrate offered. With the 'reduced' phosphorus treatment, the concentrate contained no additional mineral phosphorus, while the concentrate offered with the 'normal' phosphorus treatment contained added di-calcium phosphate so as to increase its phosphorus content.

The concentrates offered with the 'reduced' phosphorus treatment contained 38% (winter period) and 46% (summer period) less phosphorus than the concentrate offered with the 'normal' phosphorus treatment. With the 'reduced' phosphorus treatment, the phosphorus content of the total diet was 25% (winter period) and 16% (summer period) lower than for the 'normal' phosphorus treatment. The phosphorus level in the 'normal' phosphorus diet was similar to that used on Northern Ireland dairy farms at the time the study was initiated.

Table 1. Phosphorus content of the concentrates offered, and of the total diet, with the 'normal' and 'reduced' phosphorus treatments (g/kg dry matter)

	Normal phosphorus treatment	Reduced phosphorus treatment	Reduction in phosphorus content (%)
Winter period			
Concentrate phosphorus content	7.1	4.4	38%
Total diet phosphorus content	4.8	3.6	25%
Summer period			
Concentrate phosphorus content	6.7	3.5	46%
Total diet phosphorus content	4.2	3.6	16%

Intakes

Rumen bacteria require phosphorus to grow. If the diet of a dairy cow contains insufficient phosphorus, the rumen bacteria may not grow properly and this can result in reduced feed intake. However, in this study level of

phosphorus in the diet had no effect on feed intake, and this suggests that dietary phosphorus levels were adequate to maintain rumen function (Table 2).

Table 2. Effect of phosphorus level in the diet on dry matter intake during the winter periods in each of lactations 1-4 (kg/cow/day)

	Normal phosphorus treatment	Reduced phosphorus treatment
Lactation 1	17.6	17.4
Lactation 2	19.9	19.6
Lactation 3	20.8	19.8
Lactation 4	22.9	22.7

Milk Production

Milk production was unaffected by level of phosphorus in the diet in this experiment (Table 3). In addition, phosphorus level had no effect on milk composition. However, milk yields have been reduced in other studies when dietary phosphorus levels were less than 3.2 g/kg (dry matter basis).

Table 3. Effect of phosphorus level in the diet on full lactation milk production during each of lactations 1-4 (litres/cow)

	Normal phosphorus treatment	Reduced phosphorus treatment
Lactation 1	7521	7474
Lactation 2	8241	8419
Lactation 3	9177	9219
Lactation 4	9002	8976

Condition Score

During lactations 3 and 4, cows on the ‘reduced’ phosphorus diet had a slightly lower condition score than those on the ‘normal’ phosphorus diet.

However, as this was not accompanied by either a lower intake or a lower milk yield, it is unlikely to have been caused by level of phosphorus in the diet.

Blood

It is generally accepted that blood phosphorus levels do not provide a good indication of the phosphorus status of a cow. Blood phosphorus levels were lower with cows offered the 'reduced' phosphorus diet throughout the experiment, but were not at levels which suggested that cows experienced any long term phosphorus deficiency.

Bones

Dairy cows have large stores of phosphorus in their bones and they can make use of this bone phosphorus during periods when the level of phosphorus in the diet is inadequate. This will have the effect of reducing the level of phosphorus in bone, and could eventually result in weak bones which are more susceptible to breaking. However, bone samples taken from cows culled during the study indicate that both diets contained sufficient phosphorus to maintain normal bone phosphorus levels.

Cow Health

Dietary phosphorus level had no effect on the incidence of either lameness or mastitis.

Fertility

Many people believe that there is a link between dietary phosphorus levels and dairy cow fertility. While it is true that cows that are deficient in phosphorus may have poorer fertility, phosphorus deficient cows will also have lower intakes and produce less milk. Within the current study dietary phosphorus level had no significant effect on any of the fertility measurements recorded (Table 4).

Table 4. Effect of phosphorus level in the diet on dairy cow fertility (mean of four lactations)

	Normal phosphorus treatment	Reduced phosphorus treatment
Cows that had their first observed heat within 6 weeks of calving	59%	62%
Days to first observed heat	23	25
Conception to first AI	37%	34%
Conception to first + second AI	67%	60%

However, it is recognized that the number of cows on this experiment was inadequate to really identify if dietary phosphorus level had an effect on cow fertility. This is also a weakness of every experiment undertaken in the past. To overcome this problem, researchers in the US examined the combined fertility results from 13 individual experiments (involving a total of 785 cows). When reproductive performance of cows offered 'Low' and 'High' phosphorus diets were compared, level of phosphorus in the diet was found to have no effect on any measurement of fertility performance (Table 5).

Table 5. Average fertility performance across 13 studies involving high and low phosphorus diets (from Wu and Satter, 2000)

	Low phosphorus (average 3.6 g/kg DM)	High phosphorus (average 5.0 g/kg DM)
Days to first heat	47	52
Days from calving to pregnancy	103	102
Number of services/conception	2.2	2.0
Pregnancy rate (%)	92	85

Manure Phosphorus Excretion

Reducing the phosphorus content of dairy cow diets will reduce the amount of phosphorus excreted in manure. In the current experiment offering a diet containing a 'reduced' phosphorus level reduced the amount of phosphorus excreted in manure from 75 to 41 g/cow/day, a 45% reduction (Figure 1).

In addition, when cows were fed diets containing lower phosphorus levels, the phosphorus in their manure was found to be less soluble, and thus less likely to be washed into watercourses when slurry was applied to pastures.

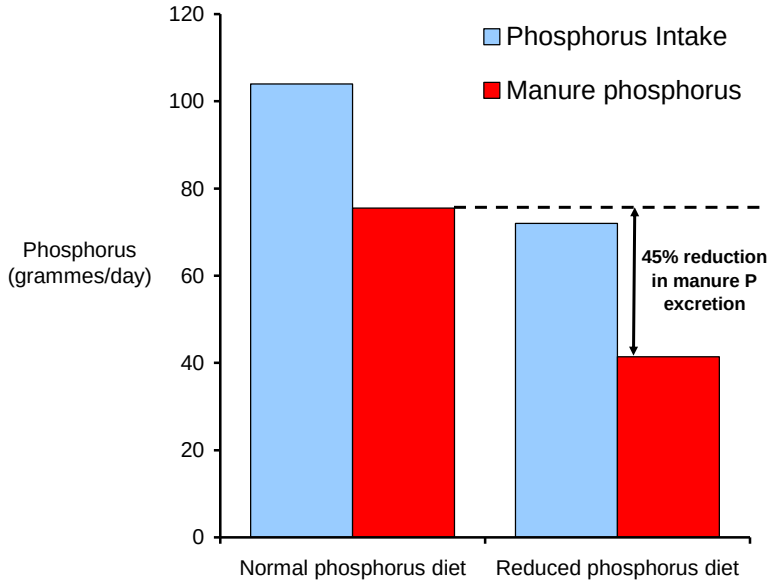

Figure 1. Effects of dietary phosphorus content on phosphorus excreted in manure

■ Formulating Diets With Lower Phosphorus Levels In Practice

Before this experiment commenced, a survey indicated that concentrates being fed to cows in Northern Ireland contained on average 7.1 g phosphorus/kg dry matter (6.2 g fresh basis). The results of the current experiment confirmed that there was no justification for dairy cow concentrates to contain such high phosphorus levels. Recognizing this, an agreement was reached within the feed compounding sector within Northern Ireland that dairy cow concentrates would not contain in excess of 6.7 g

phosphorus/kg dry matter (5.7 g/kg fresh basis). This was a positive move. However, with grass silage based-diets there is potential for this value to be reduced further, perhaps to 4.8–5.5 g/kg (fresh basis).

It is of course the phosphorus content of the total diet (not just the concentrate) that is important. Table 6 summarizes the current research evidence concerning total diet phosphorus levels for dairy cows. Evidence from this study, and from research undertaken elsewhere, suggests that total diet phosphorus levels can be reduced to 3.6-3.8 g phosphorus/kg (dry matter basis) without having a detrimental effect on cow performance.

Table 6. Summary of research evidence concerning total diet phosphorus requirements for dairy cows

Level of phosphorus in the total diet	Research evidence
Greater than 3.8 g/kg DM	Adequate in all studies; overfeeding?
3.6 – 3.8 g/kg DM	Adequate in AFBI study and virtually all other studies; risk of deficiency very small
3.3 – 3.5 g/kg DM	Inadequate in some studies: some risk of deficiency
2.7 – 3.2 g/kg DM	Inadequate in many studies: high risk of deficiency
2.2 – 2.6 g/kg DM	Inadequate in all studies: very high risk of deficiency

Nevertheless, it can be more expensive to produce concentrates containing lower phosphorus levels. This is largely due to the fact that lower cost ingredients such as maize gluten must be replaced to some extent by more expensive ingredients such as soybean meal. In addition, it can be difficult to formulate diets that are very low in phosphorus unless the phosphorus content of the forage part of the diet is known accurately. Unfortunately at present there appears to be no rapid low cost system for determining the phosphorus content of forages with a high degree of accuracy, although Near Infrared Reflectance Spectroscopy (NIRS) can provide useful information.

■ Options For Reducing Farm Gate Phosphorus Balance

A ‘farm gate’ phosphorus balance is the difference between the amount of phosphorus brought onto the farm in one year (for example, in fertilizer and

feeds) and the amount of phosphorus removed from the farm in one year (for example, in milk, cull cows and calves). The phosphorus balance on a farm will be influenced by a wide range of factors, including stocking rate, concentrate feed levels and milk production per cow. Some options by which the phosphorus surplus on your farm can be reduced include:

Feed a 'Lower Phosphorus' Concentrate

Purchasing a concentrate with a lower phosphorus level, as described in this paper, may be part of the solution. The effect of reducing the level of phosphorus in the concentrate on overall farm phosphorus balance is illustrated in Figure 2.

In this example, when the phosphorus content of the concentrate was reduced from 5.8 g to 3.8 g/kg fresh basis, the annual phosphorus balance for the farm was reduced from 14.4 kg/ha to 5.8 kg/ha. This example clearly highlights the potential of offering concentrates containing reduced phosphorus levels as a means of reducing the phosphorus surplus on a farm.

However, it is also important to take account of the level of phosphorus in the forage component of the diet, and consequently this approach should be discussed with your advisor/nutritionist.

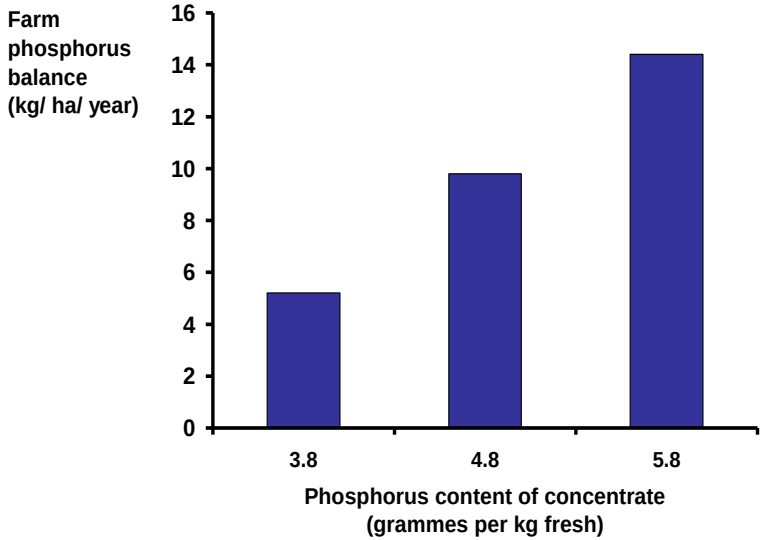

Figure 2. Effect of the phosphorus content of the concentrate on farm phosphorus balance

Feed Less Concentrates

On some farms cows are overfed concentrates. While this will have an adverse effect on profitability, it will also result in additional phosphorus being imported onto the farm. Improved concentrate allocation strategies are required.

In general, if concentrate feed levels are less than 2.0 tonnes/cow/year, an annual farm phosphorus balance of less than 10.0 kg/ha should be relatively easily achieved (provided little phosphorus fertilizer is used). However, this becomes more difficult on farms feeding in excess of 2.5-3.0 tonnes concentrate/cow/year, especially if fertilizer containing phosphorus is also purchased.

Substitute Purchased Concentrates With Home Grown Cereals

This will reduce the quantity of phosphorus imported onto the farm in concentrates.

Purchase Less Phosphorus Fertilizer

Phosphorus fertilizer should only be applied where there is a crop requirement.

Export Slurry

When appropriate, slurry can be exported to other farms.

Reduce Stocking Rates

Reduce stocking rates, either by increasing land area or reducing stock numbers. This may be the only viable option on some highly stocked farms.

■ Conclusions

In many countries dairy cows are ‘overfed’ phosphorus, and as such there is scope to reduce phosphorus levels in dairy cow diets. Most scientific evidence suggests that dairy cows can be offered diets containing between 3.6 – 3.8 g phosphorus/kg DM, without having any adverse effects on cow performance.

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