Assessing phosphorus overfeeding in dairy cows

By

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LICENTIATE THESIS

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Abstract

Faecal total phosphorus (TP) from dairy cows consists of a largely insoluble fraction and a soluble P fraction (SP), which mainly represents excess P. The soluble fraction increases proportionately with increased P feeding as excess P is mainly excreted with the faeces in soluble form. Determination of the acid-soluble P fraction in faeces has been suggested as a useful tool to identify excessive P feeding.

The overall aim of this licentiate thesis was to gain a better understanding of how different fractions of faecal samples can be used as tools to map P (over)feeding in dairy cows.

Paper I studied faecal excretion of different P fractions in 42 dairy cows fed a wide range of rations with varying P content ranging from approximately 70% up to 190% of their requirement. Faecal excretion of TP and SP was determined. The slope of the regression indicated that there was a significant relationship between actual measured SP and indirectly calculated regulated P. TP and SP were correlated and it was suggested that they can both serve as markers of P overfeeding

Paper II screened intake and faecal excretion of P on Swedish commercial dairy farms, with special emphasis on comparing farms with organic (N=14) and conventional (N=15) production systems. In each herd, intake of P and other nutrients in feeds was determined for 10 cows in varying stages of lactation. Milk yield and faecal content of P (TP and SP) were also determined for these cows. The results indicated that cows in both management systems consumed more P than they required. However the level of overfeeding was higher for cows in conventional systems. Pooling faecal samples from lactating cows improved the correlation between faecal P concentration and calculated P requirements. SP and TP appeared to be equally good in reflecting P intake relative to predicted requirement. It was shown that slurry samples could be used to evaluate P feeding on herd level.

In conclusion, this thesis showed that P overfeeding is greater in conventional dairy herds than in organic dairy herds and that both SP and TP in faecal samples can be used as markers of P overfeeding in dairy cows.

Keywords: Dairy cow, phosphorus, faeces, organic management

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Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Nordqvist, M., Spörndly, R., and Holtenius, K. Fecal phosphorus excretion in lactating dairy cows. *Submitted.*

II Nordqvist, M., Holtenius, K., and Spörndly, R. Methods for assessing phosphorus overfeeding on organic and conventional dairy farms. *Submitted.*

Licentiate degree

The Licentiate degree, which requires two years of full-time postgraduate study, is intended to guarantee, by means of course work and the completion of a dissertation, that the recipient

- has demonstrated an ability to investigate and to solve problems scientifically;
- is conversant with general scientific methodology and is familiar with the more important research methods within his or her subject area;
- is knowledgeable within his or her area of expertise and has contributed to the development of this area through his or her own research ;
- is able to utilise the scientific literature within the subject area and relate it to his or her research results;
- has in the planning and execution of research, as well as in the analysis of results, worked both independently and in cooperation with others;
- has experience in presenting and discussing research results, both orally and in writing, e. g., before a board of examiners at a final public seminar.

Abbreviations

CS	Conventional management system
DMI	Dry matter intake
ECM	Energy corrected milk
LP	Lactation period
NorFor	Nordic Feed Evaluation System
NRC	National Research Council
OS	Organic management system
SP	Soluble phosphorus
TP	Total phosphorus

1 Introduction

1.1 Dietary requirement of phosphorus

On earth, phosphorus is a fundamental chemical element for all life forms present in every cell, e.g. within DNA. No other mineral is known to have as many functions in the metabolism as P. In animal production globally, P deficiency can cause large economic losses. In Sweden, when common feedstuffs are used P deficiency in animals is rare, and oversupplementation is more common. It is not economically sound to feed P in excess, and it is also not environmentally defensible, since inorganic P is mined from finite resources (Cordell et al., 2009). Animals do not benefit from excess P, so while they should not be fed below their requirements, their P intake should be optimised to meet these requirements. The P requirement and P utilisation by the animal are a function of several factors, such as growth, milk yield, stage of lactation and the dynamics of P transfer to and from the body reserves of the animal (Wu et al., 2001; 2000). The main store in the body of cows is the skeleton, where around 80% of the P is stored and released together with Ca (Ekelund, 2003; McDowell, 1992) regulated by the same mechanisms.

Although some absorption of P occurs in the rumen, it is marginal relative to the absorption in the small intestine (Valk et al., 2000). When the P uptake in the small intestine is higher than the requirement of the cow, the P is transported with the blood to the salivary glands, where P excretion in the saliva occurs. The microorganisms in the rumen need a constant supply of P in soluble form, which is provided by the saliva. The P recirculates via the blood and the saliva to ensure a reliable and uniform P supply to the rumen microorganisms (Figure 1). The microorganisms in the rumen also require a certain concentration of P in feed in order to be productive. If the feed is too low in P, the concentration of P is lowered in the saliva and the microorganisms become less effective, which for the cow results in poor appetite and lowered milk production. The feed efficiency is also reduced. Ramirez-Perez and Meschy (2005) proposes 7 g P/kg fermented organic matter as the requirement for normal rumen function.

The amount of P varies in different feed sources. For cereals and rapeseed the concentration is high, 4-14 g/kg DM, but the P in cereals is to a large extent bound to phytate, which makes it unavailable for monogastrics. Therefore phytase is commonly added to pig and poultry rations so that the animals make more effective use of the feed P. However for ruminants, microorganisms in the rumen have the ability to make the phytate-bound P available by the production of phytase, so there is no reason to add phytase to ruminant diets.

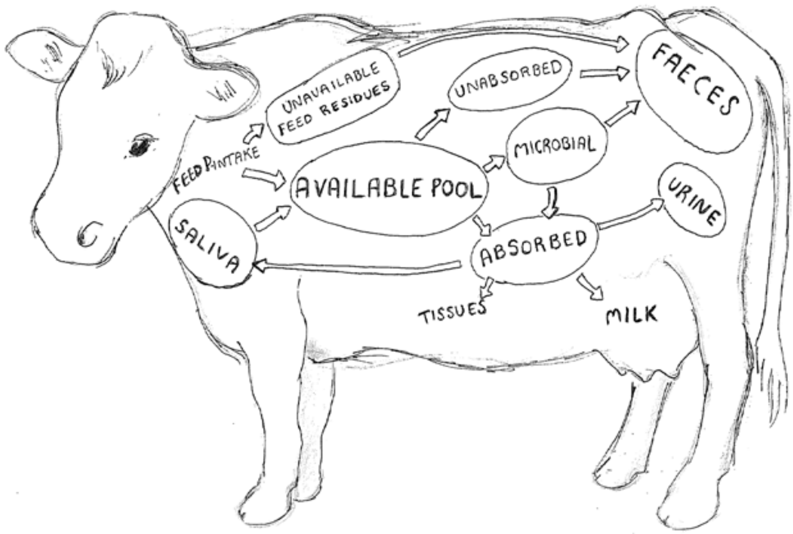

Figure 1. An illustration of P partitioning in lactating dairy cows linked with faecal P excretion. After Dou, 2010, illustration by Maria Nordqvist.

In contrast to monogastrics, ruminants do not excrete surplus P in urine and the surplus P is excreted with faeces instead (Wu et al., 2000). Increasing dietary P levels through the use of P minerals not only leads to a higher concentration of P in the faeces but, more importantly, increases the amount and proportion of P that is water-soluble and thus most susceptible to leaching to the environment (Dou et al., 2002). Dairy manure from cows fed two different dietary P levels was compared in a study by Ebeling et al. (2002). The manure was applied to different maize plots subjected to simulated rainfall and the runoff was collected and compared. The results showed a marked difference in water-soluble P between the plots. Thus addition of inorganic P to dairy diets in excess increases the potential for P runoff losses.

Surplus P is applied to the soil with the manure and either used by the crop or, if in excess, subjected to runoff losses with rainfall. When manure P is applied to fields accumulates in the soil, it increases the risk of eutrophication in water systems. The eutrophying effects of P losses with manure relate not only to the amount of P applied to fields, but also to how easily the manure P is dissolved in rainwater and subjected to potential runoff (Kleinman et al., 2002). The chemical forms of P and their relative proportions in manure also play an important role.

To reduce pollution, cows should be given no more P than they require for production. To establish how much P the cow needs, the P fractions in faeces can be studied. Determination of total P (TP) in faeces includes a largely insoluble fraction (plant cell wall residues, microbial residues, sloughed gastric intestinal cells and digestive secretions) and a soluble P fraction (SP), mainly representing excess P (Spiekers et al., 1993).

Spiekers suggests that there is an inevitable loss of P strongly correlated to the dry matter intake (DMI) and also that a certain proportion of the P consumed is always unavailable for digestion and absorption. Using standardised factors for inevitable P losses and unavailable P, he formulated a theoretical function for the P balance where the amount of P regulated in the faeces could be calculated. The P balance found in Papers I and II was compared against this theoretical P balance (Spiekers et al., 1993).

The inorganic, water-soluble fraction of P largely represents P fed in excess of animal requirements, as suggested by Dou et al. (2002). The content of soluble P in faeces increases as more P is fed and the increase in soluble P accounts for most of the increase in faecal P. Therefore water-soluble P content in faeces samples may serve as an indicator of excessive P feeding on farms (Dou et al., 2007). By acidifying the faeces sample with a solution of HCl, interfering effects of Ca and pH in samples are removed, and the determination of acid-soluble P improves the assessment method (Dou et al., 2007; Chapuis-Lardy et al., 2004). Therefore a faecal test on 0.1% HCl extract P would have potential for use as a management tool for assessing P overfeeding on dairy farms, when used together with a benchmark representing adequate P status (Dou et al., 2010).

1.2 Current P recommendation

Many studies have shown that dairy cows are often fed more P than they require according to current recommendations (Nennich & Harrison, 2008; Knowlton et al., 2004; Valk et al. 2002; Wu et al., 2001). Swedish dairy cows excrete about 5500 tonnes of P in the faeces every year (SJV, 2011; Swedish Dairy Association 2012a)

One step towards reducing P losses is to reduce the amount P in livestock feed without compromising the health of the animals. In recent decades several countries, for example Germany, the Netherlands, Denmark and the USA, have lowered their P recommendations thanks to studies showing oversupplementation of P. After studies by Ekelund (2003), the Swedish system lowered the recommendation by 11% (Spörndly, 2003; 1999).

The Nordic Feed Evaluation System for cattle (NorFor) was developed in a joint project by the farmers advisory organisations in Denmark, Iceland, Norway and Sweden in order to create a new feed evaluation system that was identical in all four countries and thus to facilitate communication between farmers, consultants and researchers (Volden, 2011). The NorFor system involves a more detailed basis for calculating the P requirement, but does not further reduce the recommended P allocation for dairy cows. For a standard-sized heifer with 30 kg milk production and gaining 0.3 kg live weight per day in the beginning of pregnancy, NorFor recommends 72 g P/day or 0.35% of feed DM (Volden, 2011). For the same type of animal 71 g/day was recommended by the previous Swedish system (Spörndly, 2003).

In the USA, the Nutrient Requirements of Cattle (NRC) approach is the dominant feed evaluation system. The P requirements are based on DMI and milk production. Compared with previous recommendations (NRC, 1989) the current system reduces the P intake by about 8% for a typical lactating dairy cow (NRC, 2001). It also recommends a P level of 0.35% of feed DM for a standard-sized heifer, as described above.

1.3 Organic versus conventional management

Swedish organic dairy production has to use 100% organically produced feeds (KRAV, 2012). In Sweden the rules for organic production also state that no mineral fertiliser should be used for crops.

Compared with conventional production, organic dairy production is characterised by a higher roughage/concentrate ratio in the diet, and feeding of roughages ad libitum. The total daily dry matter (DM) proportion of concentrate should not exceed 50% during the first three months of lactation and thereafter not more than 40% (KRAV, 2012).

Today there are 629 organic dairy farms in Sweden (12% of dairy farms) and these produced 29,944 tonnes of milk in the year ending February 2012, which was 14% more than in the previous year (Swedish Dairy Association, 2012b). A problem in supplying milk production by organic dairy cows with nutrients is that there is limited availability of commonly used protein feeds such as soybean products that are organically certified. A protein source that can be grown locally and which is used to a large extent in dairy feeding today is rapeseed and its by-products. However the P concentration in rapeseed cake is high and the P content in rapeseed meal (14 g/kg DM) is about twice that in e.g. soybean meal (7 g/kg DM). By replacing soybean products with an isonitrogenous amount of rapeseed cake in a typical diet for lactating cows, the daily P intake may increase by more than 20 % (NRC, 2001).

2 Aims of the thesis

- To study faecal excretion of different phosphorus (P) fractions in dairy cows fed a range of rations with varying P content

- To study whether different P fractions in faeces can be used as tools to map possible P overfeeding in dairy cows.

- To screen P intake and faecal excretion in Swedish commercial dairy farms.

- To compare organic and conventional dairy production systems with regard to P intake and excretion.

3 Materials and methods

This thesis is based on two studies, one experimental (Paper I) and one in the field (Paper II). The experimental study was performed at Kungsängen Research Centre in Uppsala. In the field study, 29 commercial dairy farms situated in south-east Sweden were visited. Both studies were approved by the Uppsala Local Ethics Committee.

3.1 Paper I

3.1.1 Experimental design and animals

Paper I included 42 dairy cows of the Swedish Red Breed in their mid and late lactation. They were fed to cover their energy requirements, according to Swedish recommendations for dairy cows (Spörndly, 2003) and housed indoors in a free-stall barn at Kungsängen Research centre with automatic milking system AMS (De Laval, Tumba, Sweden). They were randomly assigned to one of three diets that differed with regard to forage proportion on a DM basis. The experiment was part of a long-term study (Patel et al., 2011) in which the forage proportions were gradually increased from month 4 of lactation until drying off from 40% to 50%, from 50% to 70% and from 50% to 90% over the lactation for the three treatments, respectively. The cows were equipped with neck transponders and had access to two separate feeding areas, each with a feeding station for concentrate (De Laval, Tumba, Sweden) and 10 forage mangers placed on weighing cells (BioControl, Rakkestad, Norway), for control and recording of individual feed intake. The cows had free access to water cups and salt licks.

Half the cows (21) were fed a P-enriched concentrate and also a virtually P-free mineral blend. The feed rations were adjusted once a week according to treatment group. The experimental design generated a large variation in P level irrespective of stage of lactation. For the nutritional values of the feeds, see Table 1 in Paper I.

3.1.2 Sample collection and laboratory methods

When the cows had adapted to the diet (after at least 14 days on the specific diet), sample collection was performed during a five-day period. Samples of feed offered were collected. Silage samples were collected daily and pooled to generate weekly samples and concentrate samples were collected weekly. Grab samples of faeces were collected in the mornings and afternoons during the collection period and frozen at -20 °C. After each collection period, the samples were thawed and the 10 samples from each cow were merged and thoroughly mixed. A representative sample was then freeze-dried and stored until analysis of content of DM, minerals, ash and acid insoluble ash (AIA). The apparent digestibility of phosphorus and organic matter was determined indirectly using the AIA in the feed and faeces as an indigestible marker (Van Keulen & Young, 1977).

Milk yield was recorded automatically at each milking. Samples for analysis of milk composition were taken once every two weeks, with a 24-hour interval.

Samples for analyses of fat, protein and lactose concentrations were preserved with bronopol (VWR International AB, Stockholm, Sweden) and stored at +4 °C. The concentrations were determined by infrared spectroscopy using MilkoScan FT120 (Foss, Hillerød, Denmark). Energy-corrected milk (ECM) was calculated according to Sjaunja et al. (1990).

3.1.3 Calculation of regulated P

Daily faecal excretion of regulated P was calculated according to Spiekers et al. (1993) using this model:

Intake P (g/day) – milk P (kg milk/day * 0.00089) – inevitable P losses (0.9 * DMI) – unavailable P (P intake g/day * 0.15) – urine P (1 g/day)

3.2 Paper II

3.2.1 Experimental design

During the winter of 2009-2010, 14 organic and 15 conventional farms were visited once. All cows were housed indoors during the period in which the experiment was performed. The farms chosen had participated in an earlier field study (Fall et al., 2008). All 40 farms which took part in the earlier study (20 conventional, 20 organic) were invited to participate and 29 of them agreed. All farms with one exception, were in the Swedish official milk recording scheme.

Within each herd, 10 cows in different stages of lactation were selected for faecal sampling. These comprised three cows in early lactation (from parturition until 3 months postpartum, LP 1); three cows in mid-lactation (4-5 months after calving, LP 2); two cows in late lactation (8-10 months after calving, LP 3); and two dry cows less than two months before expected calving (LP 4). Faecal samples were obtained from each cow by rectal grab sampling, stored at -20 °C and handled individually throughout laboratory analysis. Samples of bulk stored slurry were taken on 26 of the farms and stored at -20 °C. This slurry was a mixture of faeces, urine, bedding, some feed residuals and in some cases rinse water from the milking system. Slurry samples were taken from the slurry storage tank after stirring with the pump for at least 10 minutes.

Daily feed consumption of the 10 selected cows on each farm was recorded during a 24-h period by weighing individual feed allocations or, when cows were fed in groups, by weighing the feed allocated to the group and dividing it by the number of animals. When a feeding wagon equipped with a computerised scale was used, the amount of feed was obtained from the computer. Samples of all feeds used were taken from the feeding table or from the stored feed. All forage and grain samples collected were stored at -20 °C.

Data on daily milk production by the selected cows were obtained from the official milk records closest in time, not exceeding 14 days from the visit. Data on aspects of the dairy herd, such as herd size, average yearly milk production data, cow breeds and the calving date of each cow, were collected from the Swedish official milk recording scheme.

3.2.2 Sample collection and laboratory methods

After thawing, a subsample of the faeces was taken and immediately refrozen to -80 °C, followed by freeze-drying and grinding in a hammer mill using a 1-mm sieve (Kamas, Malmö, Sweden). Thereafter the samples were stored until analysis of TP. The remainder of the faeces stored at -20 °C was thawed before analysis of SP. The feed samples and the samples from the slurry storage tank were thawed, dried at 60 °C overnight and ground in the same mill as the faecal samples.

In order to describe the general ration composition of the feeds, data on the composition of the concentrates were taken from the feed declarations by the manufacturers. The composition of roughages and other feeds produced on the farm was determined by commercial proximate analysis using the NIR method (Eurofins, Lidköping, Sweden). The nutrient values of interest were: content of DM, P, calcium (Ca), magnesium (Mg), metabolisable energy (ME), crude protein (CP), neutral detergent fibre (NDF) and estimated amino acids absorbed in the duodenum (AAT, calculated as described by Madsen et al. (1995).

Table 1. *Overwiew of Papers I and II.*

Study	1	2
Number of herds	1	29
Number of cows	42	290
Feed intake determined	x	x
Apparent digestibility of P estimated	x	
TP[1] in faeces	x	x
SP[2] in faeces	x	x
TP in slurry		x

[1]TP Total phosphorus

[2]SP Soluble phosphorus

3.3 Laboratory methods used in Papers I and II

An overview of Papers I and II is presented in Table 1. To analyse the soluble P fraction (SP) in faeces the method described by Dou et al. (2007) was used, with a slight modification. In brief, 5 g faeces were mixed with 95 mL 12 mM HCl solution and shaken in a tumble shaker for 1 h, after which the mixture was centrifuged at 1800 g for 5 min, filtered through Whatman 42 paper and inorganic P was measured using a commercially available colorimetric kit (PH 1016 RANDOX, 2010 Crumlin, UK).

The TP concentration in feed, faeces and slurry samples was analysed by plasma emission spectrometry at an accredited commercial laboratory (Agrilab, Uppsala, Sweden).

Dry matter content of the feeds and faeces was determined by overnight drying at 105 °C and ash content was determined by heating the samples to 550°C for 3 h. In order to adjust for losses of volatiles, silage DM was corrected as described by Rammer (1996). Conventional chemical analyses of the feed: DM, NDF, ADF, lignin, CP, water-soluble carbohydrates and calculations of ME were performed as described by Bertilsson & Murphy (2003).

3.4 Calculation of the P recommendation

The P recommendation for each cow was calculated for one day according to NRC (2001) and the Nordic Feed evaluation system NorFor (Volden, 2011). The P requirement according to NRC is expressed as part of daily feed DMI, while the P requirement according to NorFor uses daily milk production, body weight and gestation time as input and is expressed in g per day, or as a percentage of daily DM feed intake. The level is in accordance with previous Swedish and Danish recommendations (NorFor, 2007).

The P recommendation (g/day) according to NRC in Papers I and II was calculated as:

$$(\text{DMI} * 0.01 * \text{P \% of DMI}) * 1000$$

Where P as a percentage of DMI ranges from 0.22 to 0.36, according to volume of daily milk production (NRC, 2001), see Table 2.

Table 2. *NRC recommendations in percent of DM.*

Milk, kg	P, % of DM
0, dry cows	0.22
1-35	0.32
35-45	0.35
45-54.4	0.36
54.4<	0.38

The P recommendation (g/day) according to NorFor in Papers I and II was calculated as:

$$(0.03 * \text{BW}) + (1.6 * \text{ECM}) + (12 * \text{LWG}) + (0.000334\ \text{DIP2} - 0.053 * \text{DIP} + 1)$$

where LWG is live weight gain for primiparous cows, which was set to 0.25 kg, BW is body weight in kg and DIP is days in pregnancy.

3.5 Statistical analysis

The software SAS (SAS 9.3, SAS Institute Inc. Cary, USA) was used for all statistical calculations. The different models are described in Papers I and II.

4 Results

The results obtained in the different studies are summarised below. For more detailed results, see Papers I and II.

4.1 Descriptive statistics

4.1.1 Paper I

The study reported in Paper I was based on observations of 42 cows of the Swedish Red breed, 21 which were fed P-enriched concentrate. For all cows the mean BW was 630 kg and the average milk yield was 33 kg ECM per day. Dietary P ranged from 2.2-6.4 g/kg DM. The apparent P digestibility ranged from 21%-73% and was negatively correlated to the P content of the diet (r= -0.51) and to P intake in relation to that recommended by NRC (r =-0.5) and NorFor (r =-0.55).

4.1.2 Paper II

The 14 organic and 15 conventional herds studied in Paper II were of comparable size, with an average herd size of around 70 cows. In each herd, feed intake was recorded for 10 cows representing four different lactation stages and P intake was calculated. The cows were 38% Swedish Holstein and 55% Swedish Red in organic herds and 30% Swedish Holstein and 67% Swedish Red in conventional herds. Free stall systems were more common in organic herds (11 out of 14) than in conventional (8 out of 15). The feeding was managed differently depending on the housing system. Most conventional systems used separate feeding, with the concentrate fed separately from the roughage. For the organic systems, feeding a mixture or feeding the roughage separately from the concentrate were equally common. The average milk yield per cow per year was 8882 kg ECM for organic systems and 9976 kg ECM for conventional.

4.2 Total and soluble P in faeces

There were significant linear relationships between TP and SP in both studies, with 89% of the variation in TP explained by SP in Paper I and 67% in Paper II (Figure 2). Furthermore there was a significant relationship between measured SP and the indirectly regulated P, calculated using the Spiekers et al. (1993) model in Paper I (Calculated regulated P = 0.83 SP + 2.2; R^2=0.71). Thus for each 1 g increase in SP in faeces, the calculated excreted regulated P increased by 0.83 g. There were also significant positive relationships between the dietary P content and both TP and SP content. Each unit increase in dietary P concentration (g/kg of feed DM) was associated with an increase of 2.78 g faecal TP and 2.43 g SP per kg DM, see Figure 3 in Paper I.

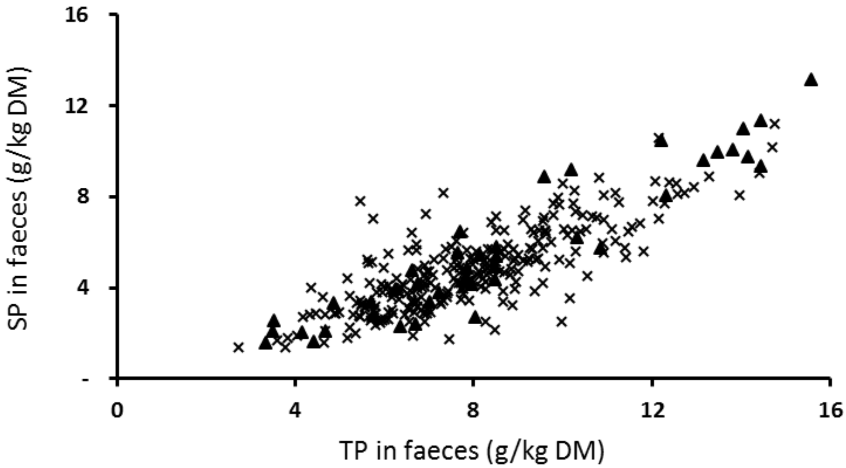

Figure 2. Total phosphorus (TP) in relation to soluble P (SP) in dairy cow faeces in Paper I (×) and Paper II (▲).

4.3 Comparison of conventional and organic dairy herds

For detailed results, see Tables 1-3 in Paper II.

On average, the cows in conventional herds were fed 11% more P than the cows in organic herds. The DMI was higher in conventional herds (22.8 kg) than in organic herds (21.7 kg). The content of TP and SP in the faeces was higher for conventional herds 29% and 36%, respectively.

There were significant differences in P excretion between the management systems during the lactation periods, but not during the dry period, see Figure 1 in Paper II.

4.4 Assessing P overfeeding

There was a linear relationship (R^2=0.82) between SP and the P requirement according to NRC (2001). Thus a P intake of 100% of the requirement according to NRC (2001) gave rise to 3.46 g SP/kg faecal DM. The relationship between SP and the P requirement according to NorFor (2007) was somewhat weaker (R^2=0.71) (Figure 3).

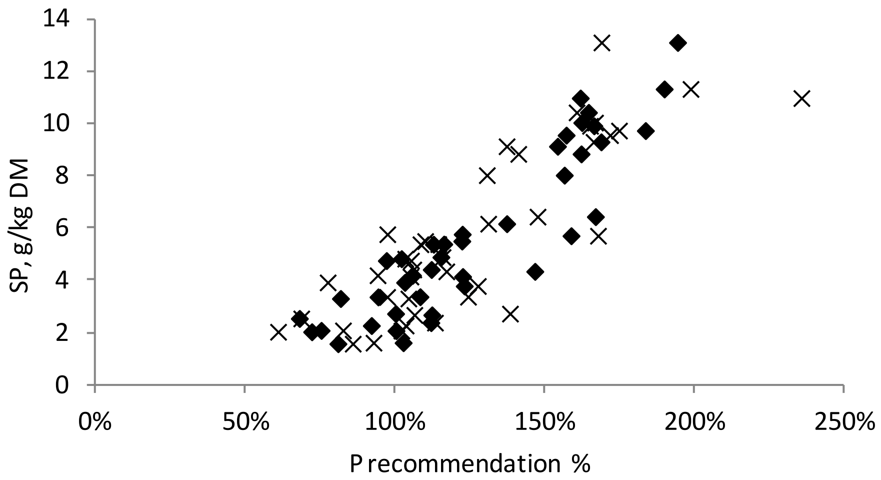

Figure 3. Soluble phosphorus (SP) in relation to P feeding rate as a percentage of the P requirement of a dairy cow calculated by the NorFor (✕) and NRC (◆) methods in Paper I.

The mean P content of the feed for all cows in Paper II was 3.7 g/kg DM, with a range from 2.1 to 5.2 g/kg DM.

The overfeeding of P was higher according to NorFor compared with NRC. The cows in organic herds were fed on average 125% of the NorFor recommendation of P and the cows in conventional herds were fed 130%. As regards the NRC P level, the organic herds were in average fed 113% of the recommendation and the conventional herds 118%.

In order to examine the accuracy of TP and SP as possible indicators of P overfeeding, the relationship between the feeding level according to NRC and NorFor and TP or SP was tested. The relationship was poor when all cows were included. The relationship between the NRC feeding level and SP or TP was stronger when only lactating cows were included. Basing the correlation coefficients on an average of 10 cows on each farm and on 8 lactating cows on each farm further strengthened the correlation.

When the diets were calculated minus the P from mineral supplement, there was still a marked overfeeding in both systems (data not shown). Without the P supplement, more than 75% of the cows were still fed above the NRC recommendations for P. In late lactation, i.e. 8-10 months after calving (LP 3), 52% of the cows in organic herds were fed over the recommendations even without the mineral supplement, as were 76% of the cows in conventional herds. For cows in earlier lactation (LP 1 and 2), the corresponding proportion of cows was even higher, while the dry cows (LP 4) received 93% of the recommendation in organic herds and 89% in conventional. Thus the dry cows were more overfed with P proportionally than the lactating cows, as can be seen in Figure 4. Lactating cows in LP 3 were least oversupplemented with P.

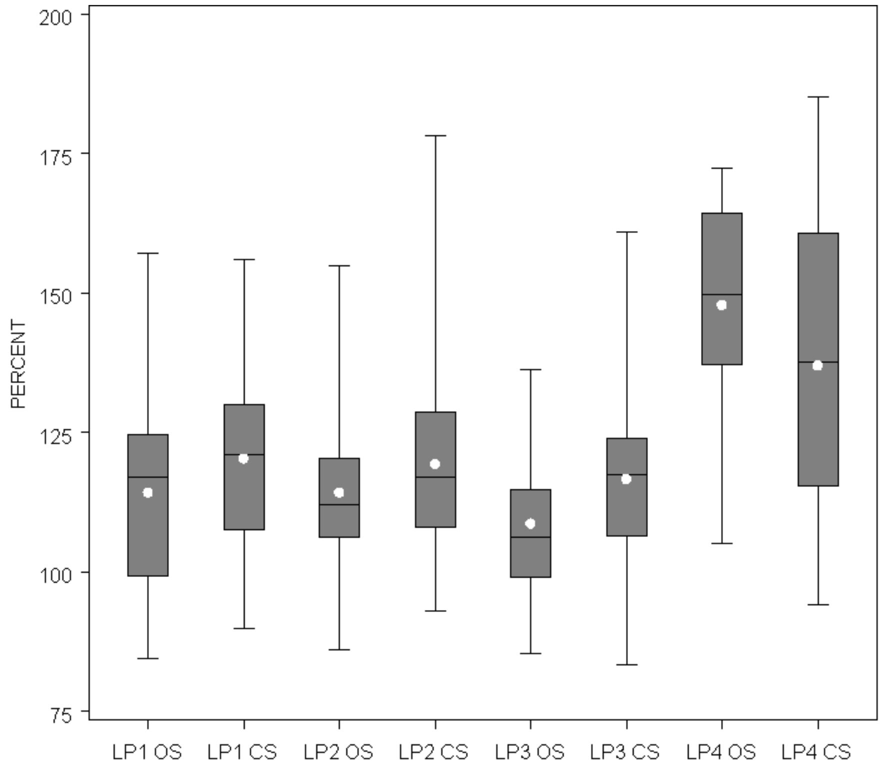

Figure 4. Boxplot of the phosphorus feeding rate as a percentage of the NRC recommendation for cows in organic (OS) and conventional (CS) system in early, mid and late lactation (LP 1-3) and in the dry period (LP 4). The white dots in boxes represent the means. The four sections of the bars represent the four quartiles.

5 Discussion

Analysis of SP in faeces has been suggested as a means to estimate P overfeeding in dairy herds (Dou et al., 2007). There is a linear relationship between SP concentration and P overfeeding according to NRC (2001) when calculated from herd data (Dou et al., 2010; Paper II) and also for individual cows (Paper I). Daily faecal excretion of regulated P, calculated according to Spiekers et al. (1993), was also correlated to measured SP (Paper I). However for each 1 g increase in SP in faeces, the calculated regulated P excreted only increased by 0.83 g. This indicates that the unavailable and/or inevitable P fractions in the diets were overestimated when the model presented by Spiekers et al. (1993) was used.

There was a strong linear relationship between the concentration of TP in faecal DM and SP in faecal DM (Paper I; Paper II). However Dou et al. (2010) did not find as strong a relationship between TP and SP in faecal DM and concluded that faecal TP may not be as effective an indicator of P supply and utilisation status as SP. The discrepancy between the results of Dou et al. (2010) and those in Paper I can probably be explained by the different nature of these studies. The study reported in Paper I was performed on one research herd, while the study by Dou et al. (2010) was based on samples from more than 90 commercial herds. Many different P sources were presumably used in the different herds included in the study by Dou et al. (2010) and these P sources may have differed in digestibility. In line with the results of Dou et al. (2010), Paper I showed a stronger relationship between TP and SP than in Paper II. The regression line in Paper II was based on data from 29 herds using a large variety of feed components. Any difference between SP and TP was to a large extent reflected by the size of the indigestible fraction, as described by Spiekers et al. (1993). It is important to underline that P fed in excess of the requirement was largely excreted as SP both in the study by Dou et al. (2010)

and in Papers I and II in this thesis. The SP fraction is thought to be the most mobile P fraction with regard to potential runoff losses (Kleinman et al., 2002).

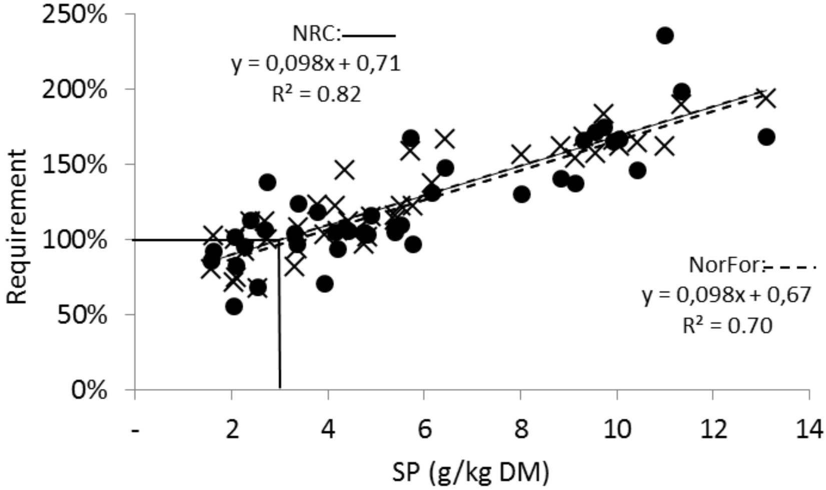

Figure 5. Soluble phosphorus (SP) in relation to the P requirement according to NRC (2001) and NorFor (2007), based on data from Paper I.

There was a linear relationship between SP and the P intake in relation to the requirement according to both NRC (2001) and NorFor (2007). A P intake of 100% of the requirement according to both NRC and NorFor should give rise to about 3.4 g SP/kg faecal DM (Figure 5). Dou et al. (2010) suggested a provisional benchmark value, with a safety margin included, of 4.75 g faecal extract P/kg (values above 4.75 g/kg indicate 15% overfeeding). The relationship between the calculated requirement and SP was weaker in Paper II, especially when all cows were included. Several factors may have contributed to this weaker relationship. For example, the information about individual feed intake was not as reliable, particularly for the dry cows, and the milk yield was only checked once monthly, which means it may have differed from the milk yield on the day of the sampling. Furthermore, one faecal sample was taken in Paper II, while in Paper I a total of 10 samples were collected during five consecutive days and merged prior to analysis, thus giving a more representative sampling of the P excretion.

5.1 Practical applications

The average TP content in faeces from 10 cows has apparently not been evaluated as a marker of P overfeeding in dairy production systems previously.

In Paper II there were significant correlations between slurry TP and P intake in relation to the requirement, both relative to NRC and NorFor, but NRC recommendations were better correlated to slurry TP than NorFor recommendations. The P intake according to the NRC recommendation was correlated to slurry P. The TP content of slurry could possibly be used as a quick indicator of excessive use of P on dairy herds. A value exceeding 6 g TP per kg DM of slurry would indicate possible overfeeding of P, because it corresponds to 100% of the NRC recommendation. As the slurry tank sometimes also collects rinse water from the milking system, there might be other sources affecting the P content of the slurry. Besides being a possible indicator of P overfeeding, analysis of the P content of slurry can also indicate its fertiliser value.

5.2 P concentration in the feed

The EU standards for organic milk production stipulate that at least 50% of the daily feed intake has to be in the form of roughage (KRAV, 2012), which generally has a lower P concentration than cereals, protein feeds and other concentrate constituents. This was also reflected in the results and was possibly one of the reasons why the organic dairy cows had a lower faecal P content.

The P concentration as a proportion of feed DM was only slightly higher for the conventional dairy herds studied, and the higher total P allocation of these herds was mainly due to the higher rate of concentrate feeding, which was 39% of the total ration, compared with only 23% for the organic herds, as the amount of mineral supplement fed did not differ between the systems. The constituents of the concentrate play an important role in P losses. Soybean meal, with a typical P content of 7 g per kg DM, can be replaced by rapeseed meal, which contain 14 g P per kg DM (NRC, 2001). However, in contrast to our expectations, it was more common for conventional herds to be fed rapeseed products than it was for organic herds, which may also have contributed to the higher P intake and excretion among conventional herds.

5.2.1 Low phosphorus intake reduced dry matter digestibility

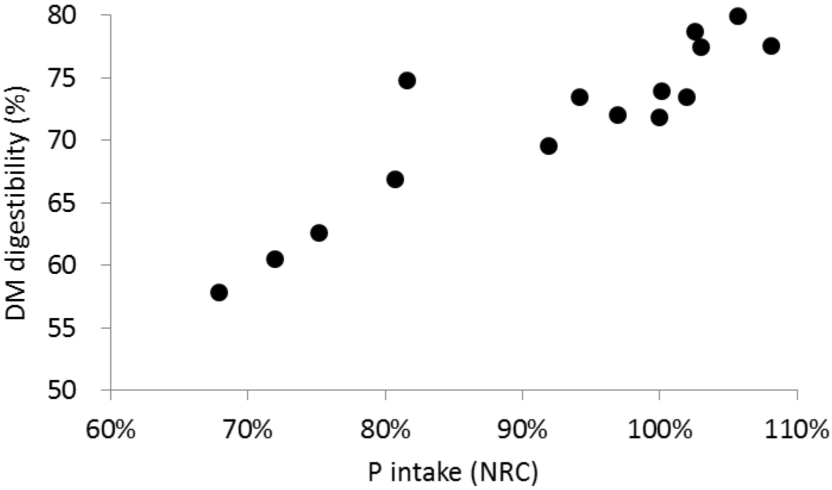

Figure 6. Phosphorus intake in percent of the NRC (2001) recommendation as a function of dry matter (DM) digestibility, based on Paper I.

As shown in Figure 6, a drop in DM digestibility occurred when the P intake went below 110% of that recommended by NRC (2001). However DM digestibility was not further improved when P intake was higher than 110% according to NRC (2001) (data not shown). Ramirez-Perez and Meschy (2005) have shown that the activity, especially of cellulolytic bacteria, is reduced when P intake is limited and that fibre degradation is compromised when the rumen concentration of available P goes below 7g/kg metabolisable organic matter. However Bannink et al. (2010) claim that P deficiency is unlikely to be a limiting factor for rumen metabolism in intensive dairy production. Further studies to determine the influence of P deficiency on rumen metabolism are warranted.

5.3 P overfeeding in Sweden

As Paper II shows, most organic and conventional herds studied were overfeeding P. Based on results for all 290 cows, the overfeeding appeared to be higher in relation to NorFor (2007) than to NRC (2001). The P recommendations in these two systems are based on different parameters and are not readily comparable. Unlike the NRC recommendation, the one according to NorFor (2007) is mainly based on expected milk yield and not on DM intake.

As mentioned above, the TP or SP for all 10 cows sampled per herd did not produce a satisfactory level of correlation. Excluding the dry cows improved the correlation to r=~0.5. Pooling the data for all cows and calculating the correlation between the overfeeding of lactating cows in the herd and the pooled analysis of SP or TP produced the best correlation (r=~0.7, see Table 4). If this were to be performed in practice, faecal samples would have to be taken from a number of lactating cows in the herd, pooled and sent as one sample for analysis of TP.

In most of the herds studied, mineral supplementation was unnecessary to meet the P requirement of the cows according to NRC. When the P in the mineral supplement was subtracted from the P content in the diet, there was still marked overfeeding of P in both systems. Without P supplementation, more than 70% of all cows were still fed above the NRC recommendations. In late lactation, i.e. 8-10 months after calving (LP 3), 52% of the cows in organic herds were fed over the recommendations even without a mineral supplement, as were 76% of the cows in conventional herds. The proportion of cows overfed P increased for cows in earlier lactation (LP 1 and 2) and in particular for the dry cows, for which the corresponding figures were 93% overfeeding in organic herds and 89% in conventional, very high figures. However their needs are small, thus lowering their P ration would have a limited impact on the P content in the slurry. Dry cows make a small part of the herd and they produce a relatively small amount of faeces. Thus it is probably more efficient to focus on lactating cows when aiming for a reduction of the P content in slurry.

These results from the 29 dairy farms studied here suggest that mineral supplementation with P is often unnecessary. Using the values from Paper II, overfeeding in Sweden compared to the NRC recommendations was estimated. If all farmers in Sweden used the same feeding levels as observed in this thesis, the total number of cows in Sweden would be supplied with 5 tonnes of excess P per day, which would mean an annual excess of 1800 tonnes (Swedish Dairy Association, 2012a).

We did not ask the farmers how much mineral fertiliser they used on their fields. Furthermore, we did not measure the total balance of P in the farm system. However, the amount of mineral feeds used did not differ between the organic and conventional systems, the concentrate allocation was lower in organic herds and, most important, no mineral fertiliser was applied to produce the home-grown forage and cereals fed to these herds. Therefore a rough estimate of the Farm Gate Nutrient Balance would result in a considerably lower P input in organic herds than in conventional. The output from the farm might therefore be lower for an organic farm. This is beneficial for decreasing the eutrophication and the pollution of the water. Milk production using dairy cattle is depending on a secure supply of clean water. The water is a resource we have to maintain and take care of for the future milk production in Sweden.

6 Conclusions

- Soluble P was the most accurate method for measuring P overfeeding in dairy cows. However, total P also reflected P overfeeding and might be as good a method in practice.

- The extent of P overfeeding in herds with organic management systems was lower than that in conventionally managed herds.

- Most of the cows in both organic and conventional systems were fed above the recommended P level.

7 Populärvetenskaplig sammanfattning

7.1 Bakgrund

Fosfor är ett nödvändigt mineralämne för människor, djur och växter. Omkring 80 % av kroppens fosfor finns i skelettet, men fosfor är inte bara en del av benvävnaden utan finns i varje cell. Inget annat mineralämne har så många kända funktioner i metabolismen som fosfor. Man har vetat sedan länge att fosforbrist kan leda till nedsatt foderutnyttjande, nedsatt mjölkproduktion och utarmning av skelettet hos mjölkkor.

I ett globalt perspektiv orsakar fosforbrist större ekonomiska förluster inom animalieproduktionen än brist av något annat mineralämne. Men det är inte någon fördel för kor att få mer fosfor än vad de behöver. De kan inte lagra ett överskott, utan det utsöndras direkt. Det är inte försvarbart, vare sig ekonomiskt eller miljömässigt, att överutfodra med fosfor eftersom det är en ändlig naturresurs. Överskottet hamnar i form av gödsel på våra åkermarker. Om vi tillför fosfor som inte binds i marken och utnyttjas av grödorna så läcker det ut i vattendrag, sjöar och hav och bidrar till algblomning med alla de konsekvenser det medför. Hur mycket fosfor som läcker beror bland annat på markens beskaffenhet, och olika fosforföreningar har varierande benägenhet att läcka. Löslig oorganisk fosfor, främst olika fosfater, orsakar vanligtvis mer övergödning än andra fosforföreningar. En stor del av det fosforöverskott som korna konsumerar utsöndras i träcken just i form av fosfater.

Omkring 12 % av Sveriges mjölkbesättningar har certifierad ekologisk produktion. En målsättning med en sådan produktion är att bedriva en långsiktigt hållbar och ur konsumentens synvinkel förtroendeingivande produktion av livsmedel så att markens och det övriga ekosystemets långsiktiga produktionsförmåga bevaras och stärks.

Syftet med detta projekt var att undersöka hur omfattande överutfodringen av fosfor är hos mjölkkor i ekologisk produktion och samtidigt göra en jämförelse med kor i konventionella besättningar. Ytterligare ett syfte var att utvärdera olika metoder som kan användas för att mäta omfattningen av överutfodringen av fosfor, såväl för enskilda kor som på besättningsnivå. De metoderna som testades var att ta träckprov från enskilda kor, samt att ta ett prov från gödselbrunnen på gården.

7.2 Utförda försök samt resultat

Två studier har genomförts inom ramen för detta licentiat-arbete. I den första studien ingick 42 lakterande mjölkkor. De flesta av dem utfodrades med en grovfoderrik foderstat, enligt principerna för kor i ekologisk produktion. Korna utfodrades med varierade mängder fosfor, från ca 70 % upp till nästan 200 % av den rekommenderade nivån. Noggranna fosforbalanser beräknades för alla de kor som ingick i försöket. I de representativa träckprover som togs analyserades både den totala halten av fosfor och den lättlösliga fraktion, som anses medföra en större belastning av miljön än andra fosforfraktioner.

Resultaten visade att såväl den totala halten av fosfor i träck, som den lättlösliga fraktionen väl speglar graden av överutfodring av fosfor. Vidare visade resultaten att vid överutfodring av fosfor utsöndras överskottet nästan uteslutande i form av lättlöslig fosfor, fosfater, det vill säga de föreningar som anses ha störst negativ påverkan på miljön.

Den andra studien som genomfördes var en fältstudie på 29 mjölkbesättningar i syd-östra Mellansverige, (i Uppland, Sörmland, Östergötland och Småland) varav 14 var ekologiska och 15 konventionella. Tio kor i varje besättning som befann sig i olika laktationsstadier valdes ut. En endagars foderkontroll genomfördes och fosforinnehållet noterades för alla de fodermedel som utfodrades i besättningen. I de fall mineralanalys av fodermedlet saknades, analyserades fosforhalten. Från de tio utvalda korna i varje besättning togs träckprover som analyserades med avseende på totalt och lättlösligt fosfor. Prov för analys av fosfor i flytgödsel togs också från flertalet besättningar. Resultaten visade att de allra flesta korna, i både ekologiska och konventionella besättningar, överutfodrades med fosfor. Men omfattningen av överutfodring var generellt mindre i ekologiska besättningar vilket delvis berodde på att kor i de ekologiska besättningarna utfodrades med en större andel grovfoder med lägre fosforinnehåll än kraftfoder. Förutsatt att korna i studien väl representerar Sveriges mjölkkopopulation, skulle det innebära att de svenska korna utfodras med ungefär 1800 ton fosfor för mycket årligen. I överensstämmelse med resultaten från den första studien, visade denna fältstudie att såväl den totala halten av fosfor i träck som den av lättlöslig fosfor väl speglar graden av fosforöverutfodring.

7.3 Praktisk tillämpning av resultaten

Metoden att bedöma utfodringsnivån i mjölkkobesättningar, genom att ta träckprov från ett antal lakterande kor och i träcken analysera lättlösligt fosfor bevisades vara säker och bra. Vår undersökning antydde att även en enklare analys av total fosfor i flytgödsel gav en godtagbar fingervisning på utfodringsnivån av fosfor. Prov från gödselbrunnen analyserades enbart med avseende på total fosfor samt torrsubstanshalt (ts). Fosforkoncentrationen i flytgödsel jämfördes med utfodringsnivån av fosfor enligt NRCs rekommendation för de tio provtagna korna i besättningen. Resultatet visade att ett värde som överstiger 6 g fosfor per kg ts i flytgödsel, motsvarar en fosforutfodring som överstiger behovet enligt NRC. Det vill säga ett värde högre än 6 g i flytgödsel, tyder på att mjölkkorna är överutfodrade med fosfor. Att analysera flytgödseln med avseende på fosfor har också fördelen att man får värdefull information om gödslingsvärdet av gödseln, utöver en indikation på fosforutfodringen. Man bör dock ha i åtanke att det kan finnas andra fosforkällor som hamnar i flytgödseln, till exempel diskvatten från mjölkningsanläggningen samt foderrester etc. En annan metod där man slipper felkällor av detta slag, men ändå kan få en indikation på fosforutfodringen på gården, är att blanda träckprover från åtta olika lakterande kor i besättningen till ett prov, som sedan skickas för fosforanalys. Den genomsnittliga fosformängden i fodret till de åtta lakterande korna per gård, i fältstudien, visade ett starkt samband med medelvärdena av total fosfor samt lättlöslig fosfor i kornas träck.

Under gårdsbesöken tog vi inte reda på mängden mineralgödsel som spreds på de konventionella gårdarnas åkrar. Vi gjorde därför ingen uträkning vad gäller den totala fosforbalansen på gårdsnivå. Men vår studie visade att mineralfoder användes i lika stor utsträckning på ekologiska och konventionella gårdar. Kraftfoderandelen var lägre i de ekologiska foderstaterna och framförallt användes inte någon mineralgödsel för att producera det ekologiska fodret. Därför tyder en grov uppskattning av fosfor balansen på gårdsnivå, på att det var en lägre total införsel av fosfor till ekologiska gårdar än till konventionella. Att begränsa fosforläckage till miljön är ett viktigt steg för att minska övergödningen, det är dessutom viktigt för att behålla den rikliga tillgången av rent vatten i Sverige, något som är fundamentalt för framtidens mjölkproduktion.

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