Baltic Forum for Innovative Technologies for Sustainable Manure Management

KNOWLEDGE REPORT

Determine Feeding Strategies for Reducing P and N Content in Manure

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Determine Feeding Strategies for Reducing P and N Content in Manure (Task 3)

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Preface

Baltic Manure (The Baltic Forum for Innovative Technologies for Sustainable Manure Management) is a Flagship Project in the Action Plan of the EU Strategy for the Baltic Sea Region (BSR), which is co-funded by the Baltic Sea Region Programme of the European Union. The work described in this report was performed within Work Package 3 (WP3) "*Innovative technology for animal feeding and housing, processing, storage and spreading of manure*" within Baltic Manure.

Phosphorus is an essential nutrient for both animals and plants. An adequate supply of phosphorus to livestock and crops is therefore important to ensure production and health. In the past, much effort has been attributed to make sure that farm animals received sufficient phosphorus to satisfy their physiological requirement. Due to low digestibility of plant phosphorus, the addition of mineral phosphate (feed phosphate) was introduced and became widely used for decades. Thus, the animals did not suffer from phosphorus deficiency but the net utilization of phosphorus was low resulting in large excretion of phosphorus.

For nitrogen the story is almost the same. The animals need protein and amino acids containing nitrogen and in former days, amino acids could only be provided by the feedstuffs. Thus, the required dietary crude protein to fulfil the animals' requirement was very high resulting in a corresponding low net utilization and great excretion of nitrogen.

Increased focus on the environment and specifically the aquatic environment has been the driving force for improvements in nutrient utilization and excretions of phosphorus and nitrogen in farm animals. This report deals with the applied changes in feeding and the potential for future reductions in the excretion of nutrients because these changes also affect manure quality regarding concentrations of dry matter, nitrogen, phosphorus, organic matter etc. An efficient use og the nutrients present in manure calls for specific knowledge on the nutrient content and on the factors affecting the nutrient content. Another focus point is that an improved utilization of the manure nutrients as fertilizer is needed because of environmental concern. Thus, it is crucial that farmers incorporate effective tools in their management systems in order to meet the targets set for the aquatic environment.

Therefore, a holistic approach regarding the utilization of nitrogen and phosphorus is needed and this report aims at the feeding methods that affect the use and excretion of nitrogen and phosphorus in farm animals. Main focus will be on means and barriers for improvements in utilization of nitrogen (protein/amino acids) and phosphorus in ruminants and pigs and to some extent also poultry.

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0 Summary

Phosphorus and nitrogen (as protein and amino acids) are, at the same time, both environmental factors and essential nutrients, yet, an adequate supply of phosphorus, protein, and amino acids is important to ensure production and health of livestock. As such, a balanced approach taking both the animals' requirement and the environment into consideration is required so that improvements in the environment do not result in poor health and production in the farm animals and vice versa.

The increase in number and productivity of farm animals in the Baltic Sea Region has for decades increased the demand for import of feedstuff, especially protein sources like soy bean meal from other continents. Furthermore, mined phosphates are introduced into the livestock sector to ensure health and productivity. This import has resulted in an increase in manure nutrient content, and in animal dense area, the import has led to a soil nutrient content that is above crop demand. However, increased focus on the environment and specifically the aquatic environment has been one of the main driving forces for improvements in nutrient utilization and derived reductions in excretions of phosphorus and nitrogen in farm animals.

The work in the Baltic manure project on feeding has focused on the potential for future reductions in the excretion of nutrients through improved feeding strategies. A more efficient use of feed nutrients in livestock farming demands specific knowledge on nutrient concentration and quality expressed as e.g. the amino acid profile of the protein in feedstuffs. Regarding phosphorus, focus is on the phytate phosphorus content of plant feedstuffs and the presence and activity of the enzyme phytase that stimulates the degradation of phytate rendering phosphate available for absorption in the gastrointestinal tract of livestock. When phytate is degraded releasing phosphate to be absorbed, the need for imported feed phosphates is lowered. Overall, this results in improved utilization and reduced excretion of phosphorus.

Improved feeding strategies are presented and tools are given aimed to decrease the need for imported feedstuffs like soybean meal and feed phosphates. Dietary crude protein can be replaced by industrially produced amino acids like lysine, methionine, threonine, and tryptophan which results in a lowered inclusion rate of e.g. soybean meal. At the same time, the increased use of microbial and plant phytase can diminish the need for feed phosphates. More precise feeding strategies like phase feeding are important tools and recently, liquid feeding has been established to be valuable to increase the digestibility of phosphorus and to some extent also protein by initiating the digestive processes previous to consumption by the animals.

Main conclusions are:

- The specific nutrient content of manure depends on the balance between dietary supply and the animals' productivity and need.
- Import of feedstuffs e.g. soybean meal and feed phosphates should be reduced as much as possible.
- Protein should be replaced by crystalline amino acids in pigs and poultry reducing the need for protein feedstuffs like de-oiled soybean meal, rape seed meal etc.
- Microbial phytase should be used to increase the digestibility of phosphorus in plant feedstuffs reducing the need for feed phosphate supplementation in pigs and poultry.
- Total mixed rations (TMR) where feeds are weighed and mixed in proper rations to fulfil the animal's requirement should be employed in dairy cattle farming.

- Phase feeding systems tailoring the dietary nutrient supply to the animal's need should be applied in the feeding of dairy cattle, pigs and poultry.

Overall, a holistic approach regarding the utilization of nitrogen and phosphorus is needed and the feeding report presents feeding methods and strategies that will increase the utilization and lower the excretion of nitrogen and phosphorus in ruminants, pigs and poultry.

1 Introduction

Manure production and its nutrient content for a specific animal or herd are to a large part a function of input and output. Input is feed and bedding materials like straw, and output is products (milk, meat, eggs etc.) and manure. Therefore, manure characteristics will be closely related to feed quality and quantity and production intensity for the particular herd. The use of manufactured protein concentrate feeds can increase production levels but since feedstuffs are not fully utilized by the animals, they also increase the amounts of nutrients excreted by the animals resulting in increased nutrient levels in manure. There are, however, a range of innovative feeding methods that can be used to balance feeding with production levels, increase in nutrient utilization and decrease the quantity of nutrients that end up in manure. Additives can be included in the feed which increase utilization of phosphorus and nitrogen. Another tool is phase or multiphase feeding, where the feeding regimes are adapted to the animals' needs but all in all, basic and practical knowledge is needed in order to implement safe means for improvements in nutrient utilization which also affect the amount of manure produced and the manure nutrient content. The opportunity for improved nutrient utilization also depends on the structural development in livestock production systems. These years, farm structure changes from smaller to bigger and bigger farm units in most countries. This is in some countries associated with an increase in production i.e. number of pigs, milk etc. whereas in other countries, the production the number of pigs goes down. However, the structural development also affects the possibilities for the farmers to adopt results and recommendations from research and development because changes from e.g. dry to liquid feeding systems require investments. Therefore, investments related to improved nutrient utilization should be considered when new barns are built or existing buildings are renewed.

The aim of the report is to describe a) the turnover of phosphorus and nitrogen in livestock production, b) ways to improve the utilization of phosphorus and nitrogen in livestock farming, and c) the potential for reducing phosphorus and nitrogen inputs to agricultural soils via manure to. This report will focus mainly on phosphorus, since unlike nitrogen (protein and amino acids) phosphorus utilization in animal production has only been considered an environmental factor in many countries since about 10 years ago.

1.1 Essential nutrients and environmental factors

Phosphorus is an essential nutrient for both animals and plants. An adequate supply of phosphorus to livestock and crops is therefore important to ensure their production and health. The element nitrogen is also essential to both plants and animals, although animals the need nitrogen in the form of protein and amino acids whereas plants need nitrogen as ammonia or nitrate. However, both phosphorus and nitrogen in manure are affecting the terrestrial and aquatic environment due to leaching, runoff, and erosion.

Animals get protein, phosphorus and other nutrients and energy form the feed and the main approach addressed has during the past decades been to make sure that the animals are fed sufficient amounts of all essential nutrients and energy. However, growing environmental concern has for the last two to three decades increased the focus on feeding measures towards reducing the excretions of nitrogen and recently phosphorus. Therefore, there is a need for balanced approaches that assure the animals get the nutrients they need to grow and produce and to ensure health and welfare. At the same time, the animals should not be fed in excess of their need because which will result in decreased utilization of the nutrients and excessive nutrient excretion. Overall, it's important to be keep in mind that the manure nutrient content and quality is affected by feed composition and feeding management.

Phosphorus is involved in many basic functions in the body related to the turnover of energy as part of the energy yielding components like ATP, ADP, and AMP but phosphorus is also important to cell wall integrity and processes like cell replication. However, up to 80% of the body pool of phosphorus is located in the bones where phosphorus together with calcium constitutes hydroxyapatite which is deposited in a collagen matrix ensuring the structural rigidity of the skeleton. Thus, shortage in phosphorus supply will result in phosphorus deficiency. The first sign of phosphorus shortage is lowered productivity and more pronounced deficiency results in weak or soft bones, and finally in broken bones. Protein and amino acids are preconditions for protein synthesis and thus body growth, milk or egg production. Deficient protein and amino acid supply will, as with phosphorus, result in reduced production and health.

The principle is that both phosphorus and nitrogen (as protein and amino acids) are, at the same time, both essential nutrients and environmental factors. This requires a balanced approach taking both the animals' requirement and the environment into consideration so that improvements in the environment do not result in poor health and production in the farm animals.

1.2 Pigs

1.2.1 Actual P and N utilization

Pigs' utilization of nutrients can be calculated based on information on feed intake, body weight gain, nutrient concentration of the feed, and the amount of nutrients that are retained in the body. In sows, information on litter size and age of the piglets at weaning is also needed (Poulsen et al., 2006). The actual utilization and excretion is given in Table 1.2.1.1.

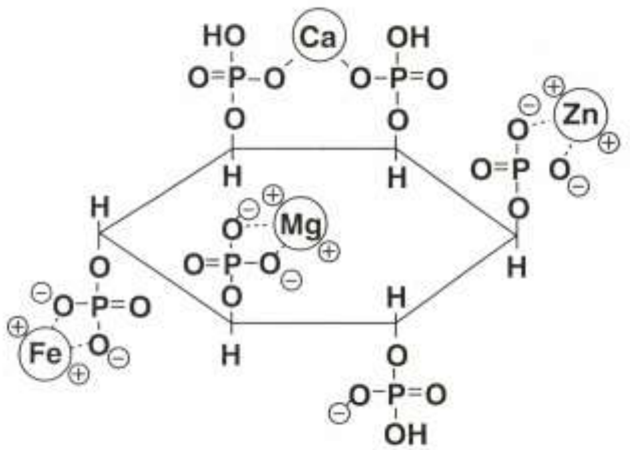
Table 1.2.1.1 Intake and excretion of phosphorus in pigs raised in Denmark (Poulsen et al., 2013)

	1 growing finishing pig 32 to 107 kg (live)	1 weaner pig 7.2 to 32 kg (live)	1 sow incl. pigs per year
Phosphorus			
Intake, kg	1.03	0.26	7.39
Retention, kg	0.41	0.12	1.82
Excretion, kg	0.62	0.14	5.57
Utilization, %	40	47	25
Nitrogen			
Intake, kg	5.06	1.26	32.87
Retention, kg	2.22	0.75	7.31
Excretion, kg	2.84	0.51	25.56
Utilization, %	44	60	22

1.2.2 Actual feeding system

Pig feed is primarily of plant origin: mainly cereals and protein sources like soybean meal, rapeseed meal or cake, and sometimes also sunflower, beans, or lupines. Plant based feedstuffs contain a lot of phosphorus which is to a large extent bound in the complex phytate (inositol phosphate) (Figure 1.2.2.1). Often, up to 80% of the phosphorus is present as phytate in pig diets. However, phytate-phosphorus is hard to digest for monogastric animals and thus the utilization of phytate-phosphorus is therefore very low. Consequently, it has been necessary to add extra mineral phosphates to pig diets in order to fulfill their requirements (see 4.4). The availability of phosphorus from phytate can be increased if the enzyme phytase is present but cereals and seeds possess different amounts or activity of phytase (see 4.5), so the actual phosphorus availability depends on the feed composition. Heat-processed oilseeds possess no phytase activity and heat-treated cereals have a lowered phytase activity compared with plain cereals. In the beginning of 1990th, microbial phytase was introduced as feed additive to stimulate the breakdown of phytate rendering phosphorus available for absorption. The inclusion of phytase is now widely used but the exchange rate between microbial phytase and mineral phosphates depends on the efficacy of the diverse commercial products. However, knowledge on this is a prerequisite for safe substitution of mineral feed phosphate (see 4.5). Proper inclusion of microbial phytase allows that the supplementation with mineral phosphates can be reduced and sometimes even completely removed. The result is that the phosphorus utilization is increased and the excretion reduced.

Figure 1.2.2.1 Intact (not degraded) phytate molecule with six phosphate groups



1.2.3 Bottlenecks (barriers) – knowledge/advice/farm adaptation

There are some obvious barriers in the quest for improved phosphorus utilization. First of all, knowledge on how to use phytase properly is required and also about which effect could be expected when a certain amount of phytase is added. Therefore, appropriate advice to farmers and feed producers is important. Another issue is that phytase should be mixed homogenously into the diets so that every kg of the diet contains sufficient phytase.

Scientific studies as well as practical observations have shown that even though microbial phytase stimulates the release of phosphate group from phytate (Figure 1.2.2.1), the digestibility of phosphorus in barley, wheat, soybean based diets do not exceed 60-65% when pigs are fed dry feed (Blaabjerg & Poulsen, 2003; Henriksen et al., 2013). This seems to be one of the limitations for improving the utilization of phosphorus in pigs. However, there are some obvious methods to overcome this bottleneck by use of liquid feeding which increases the digestibility of phosphorus (see 4.6).

Previously, the high price of microbial phytase was a barrier to tis use but as phytase is now widely used, the price is no longer an issue. At the same time, the price on feed phosphates is increasing due to the expected global shortage in phosphorus mine reserves (see 4.4).

The digestibility of protein (nitrogen) in pigs is quite high, exceeding 80% in most pig diets. However, the digestibility of protein from cereals and some protein feedstuffs high in fiber content is rather low. Therefore, it is warranted that the digestibility of such diets could be higher. Another very important issue that is decisive for reductions in nitrogen excretion is the access to industrially produced crystalline amino acids that may be used in diet formulations to replace crude protein. Table 1.2.3 shows which essential amino acids, that are commercially available to some extent (bold). However, it is important that the costs are reasonable in comparison to soybean meal, rape seed meal and other relevant protein sources.

Table 1.2.3 Amino acids – essential and non-essential in animal nutrition (Nørgaard, 2011). Amino acids marked in bold are commercially available in crystalline form

Essential	Semi-essential	Non-essential
Histidine	Arginine	Alanine
Isoleucin	Cystein	Asparagine
Leucine	Tyrosine	Aspartic acid
Lysine		Glutamic acid
Methionine		Glutamine
Phenylalanine		Glycine
Threonine		Proline
Tryptophane		Serine
Valine		

All essential amino acids that are not available in crystalline form have to be provided via the feedstuffs. This may be a bottleneck for further reductions in dietary crude protein content and thus reductions in nitrogen excretion and as well as emissions of ammonia.

Nutrient requirements (or feeding recommendations) express the average amount of nutrients that the animals in various phases of their production life would use. However, feeding recommendations are due to various reasons often not the same across countries but the trends follow the same principles, and recommendations are given predominantly as digestible amino acids/kg diet or /FEs. Table 1.2.4 shows, as an example, the current amino acid and suggested crude protein recommendation for pigs in Denmark.

Table 1.2.4. Current amino acid recommendations and suggested crude protein content for pigs in Denmark (more detailed list is available at Tybirk et al., 2013)

	Lysine	Methionine	Threonine	Tryptophan	Min. crude protein	Max. crude protein
	g digestible/FEs					
Sows:						
Pregnant	3.3	1.6	3.0	1.0	90	-
Lactating	6.6	2.1	4.0	1.3	110	-
Piglets:						
9-30 kg	10.5	3.4	6.4	2.10	144	154
Growing-finishing:						
30-45 kg	8.5	2.6	5.4	1.70	130	-
45-105 kg	7.4	2.3	4.9	1.48	115	-

Recommended maximum content of crude protein is given for piglets due to problems with diarrhea if the protein level is too high.

As mentioned, feeding recommendations are not similar for all countries. Tables 1.2.5 and Table 1.2.6 present the Finnish recommendation on protein and amino acids for different categories of pigs (https://portal.mtt.fi/portal/pls/portal/rehu_mtt.REHU_MTT_AMINOHAPPO_PACK.report?p_kieli=3).

Table 1.2.5 The Finnish recommendations on amino acid requirements of growing gilts, sows and boars

	Gilts, slow rearing			Gilts, fast rearing			Sows		Boars
	20-55 kg	55-100 kg	100 kg-insemination*	20-55 kg	55-100 kg	100 kg-insemination	Pregnant	Lactating	
Digestible crude protein (DCP) in unit of energy									
DCP, g/MJ NE	16.1	12.4	11.8	16.1	12.9	12.4	11.8	15.1	11.8
Apparent ilel digestible amino acids, g/MJ NE									
Lysine	1.02	0.65	0.54	1.02	0.75	0.65	0.54	0.70	0.54
Methionine+cystine	0.60	0.38	0.32	0.60	0.44	0.38	0.32	0.41	0.32
Threonine	0.61	0.39	0.32	0.61	0.45	0.41	0.32	0.42	0.32
% of the amount of lysine									
Methionine+cystine	59	59	59	59	59	59	59	59	59
Threonine	60	60	60	60	60	60	60	60	60

*For slowly growing gilts, the feed allowance is increased by 4.7 MJ NE/day 2 weeks before insemination. Lactation or piglet feed is recommended for this purpose.

Table 1.2.6. Finnish recommendations on protein and amino acid requirements of growing pigs

	DCP, g/MJ NE	Apparent ileal digestible AA, g/MJ NE		
		Lysine	Met+Cys	Threonine
Piglets, under 20 kg	17.2	1.02	0.60	0.61
1-phase feeding				
20-100 kg	15.1	0.89	0.53	0.54
2-phase feeding				
20-55 kg	16.1	1.02	0.60	0.61
55-100 kg	12.9	0.75	0.44	0.45
3-phase feeding				
20-55 kg	16.1	1.02	0.60	0.61
55-80 kg	12.9	0.75	0.44	0.45
80-120 kg	12.4	0.65	0.38	0.41

1.3 Poultry

1.3.1 Actual P and N utilization

Nutrient utilization in poultry can be calculated based on information on feed intake, body weight gain, nutrient concentration of the feed, and amounts of nutrients that are retained in the body. In layer hens, information on egg production (kg) and nutrient contents in eggs is also needed (Poulsen et al., 2006). Actual utilization and excretion of phosphorus and nitrogen in poultry is given in Table 1.3.1.1.

Table 1.3.1.1 Intake and excretion of phosphorus in poultry in Denmark (Poulsen et al., 2013)

	1000 broilers, 32 days	1000 broilers, 45 days	100 layers per year	100 ducks produced	100 geese produced
Phosphorus					
Intake, kg	15.5	28.3	19.4	6.34	19.6
Retention, kg	6.7	9.9	4.3	2.05	3.6
Excretion, kg	8.8	18.4	15.1	4.29	16.0
Utilization, %	43	35	22	32	18
Nitrogen					
Intake, kg	92.5	168.9	104.1	26.2	71.7
Retention, kg	52.5	87.0	37.3	9.0	15.6
Excretion, kg	40.0	81.9	66.8	17.2	56.1
Utilization, %	57	52	36	34	22

1.3.2 Actual feeding system

Poultry feed looks quite like pig feed and almost the same feedstuffs are used in poultry and pig feed. However, the specific nutrient requirements of poultry and pigs differ and the feed is optimized according to that. For instance, the need for sulfur containing amino acids is higher in poultry due to their plumage. Microbial phytase supplementation is also used to improve the utilization of phosphorus in poultry as they have the similar difficulties in digesting phytate as pigs (see 1.2.2 for details).

1.3.3 Bottlenecks (barriers) – knowledge/advice/farm adaptation

The same barriers for improved phosphorus utilization can be detected in poultry as with pigs (see 1.2.3). Industrially produced amino acids are also widely used in poultry feed and the same issues are relevant in poultry production as in pig production (see 1.2.3). However, it should be born in mind that the use of crystalline amino acids is only used in conventional production and not in organic poultry or organic pig production.

The actual feeding recommendations for poultry differ between countries but most countries have defined recommendations for the most predominant poultry categories. Tables 1.3.3.1 and 1.3.3.2 show the actual Finnish recommendations to laying hens and broilers.

Table 1.3.3.1 Amino acid and mineral requirements of laying hens

		Age			
		17-28 wk	29-45 wk	46-65 wk	65- wk
Crude protein	g/kg	175	175	175	175
Metabolizable energy	MJ/kg	11.0	11.0	11.0	11.0
Amino acids:					
Lysine	g/kg	7.6	7.6	7.6	7.6
Methionine	g/kg	3.7	3.7	3.7	3.7
Methionine+cystine	g/kg	6.3	6.3	6.3	6.3
Threonine	g/kg	6.7	6.7	6.7	6.7
Minerals:					
Calcium	g/kg	35.0	38.0	39.0	39.0
Available phosphorus	g/kg	3.5	2.9	2.5	2.3

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Table 1.3.3.2. Amino acid and mineral requirements of young chicken

		Chickens		Pullets		
		0 - 6 weeks old		7 - 20 weeks old		
Crude protein	g/kg	180	200	130	150	170
Metabolizable energy	MJ/kg	11.5	12.0	11.0	11.0	11.5
Amino acids:						
Lysine	g/kg	9.5	10.0	6.5	7.0	8.0
Methionine	g/kg	4.0	4.5	2.5	3.0	3.5
Methionine+cystine	g/kg	7.0	8.0	4.5	5.5	6.3
Arginine	g/kg	10.0	11.0	6.6	7.8	9.0
Threonine	g/kg	6.0	6.8	4.0	4.7	5.5
Tryptofane	g/kg	1.8	2.0	1.5	1.6	1.8
Histidine	g/kg	3.3	3.6	2.1	2.5	3.0
Leucine	g/kg	11.5	12	8	9	10
Isoleucine	g/kg	6.2	6.8	4.4	5.2	5.8
Phenylalanine	g/kg	6.0	6.4	4.2	4.8	5.5
Phenylalanine+tyrosine	g/kg	11	12	8	9	10.8
Valine	g/kg	6.8	7.4	5.0	6.0	6.6
Minerals:						
Calcium	g/kg	9.0	9.0	7.5	7.5	8.0
Available phosphorus	g/kg	4.0	4.5	3.5	3.5	4.0

1.4 Cattle

1.4.1 Actual P and N utilization

Physiological nutrient requirements of cattle per a year or period depend on the age, body weight, weight gain and genetic production level. Feed consumption for covering the physiological requirements is affected by the quality of feeds (nutrient concentration in feed, digestibility, edibility, tastiness etc.) and balance of a diet. Unbalanced diets and low quality feeds increase feed consumption as well as the amount of residues released to the environment (potential pollutants). Table 1.4.1.1 presents the average nutrient requirement for cattle of different age and production groups per year/period, according to the amounts of dry matter, nitrogen and phosphorus.

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Table 1.4.1.1. Average nutrient requirements of cattle per year/period, for different production and age groups

Age/production group	Nutrients				
	DM kg	Energy MJ/kg DM	Protein %	Nitrogen kg	Phosphorus kg
Dairy cows (body weight 650 kg, milk production 7000 kg)	6500	11.0	15.0	170	30
Calves (0 to 6 months)	700	12.0	16.0	37	2
Heifers (from 6 months to calving)	2900	10.5	12.5	58	9
Bullocks (from 6 months to slaughter)	3000	10.6	13.0	62	9

The amount of feeds needed to cover the physiological requirement of an animal is very variable depending on plant species used and dry matter content. The lower the dry matter content of the diet is, the greater the total amount of feed.

1.4.2 Actual feeding system

Different feeds are either offered separately, taking into account the optimal order of feeding, or all at the same time as a total mixed ration (TMR) which is blended together in a special mixer. Feeding cattle TMR has been widely spread in recent years as new loose housing type barns have been constructed. The new feeding type is based on a well-balanced diet providing animals with all necessary nutritional factors. The aim is to achieve the highest milk production of dairy cows by most profitable economic measures. Cattle feeds are generally analysed in the laboratory and are of high quality and nutritive value. Feeds are stored in conditions which preserve their nutritive value. Feeding technology (feeding strategy) is typically related to the size of the herd, properties of the feeds.

Classic feeding strategy

The classic feeding strategy is mainly used in tie stall (small) barns. The feeds are offered separately. In order to guarantee the effective use of nutrients, the optimal order of feeding should be followed. At first the tastiest feeds (concentrates, oil meals) should be given, followed by basic feeds (silage, hay). Daily diet is usually divided into 2 or 3 feedings. Attention should be paid to the distribution of big quantities of concentrates. Recommendable quantity of concentrates to a dairy cow should not exceed 3 kg per feeding. Due to the peculiarities of the digestive physiology of the cow, feed protein is rapidly degraded to ammonia in the rumen and used by the rumen micro-organisms for the synthesis of their body proteins. Feeding big amounts of concentrates, the forming of ammonia is so intensive that the rumen micro-organisms are not able to bind it all. Excessive ammonia is removed from the organism mainly in the form of urine urea. The result is that the efficiency of the use of protein is reduced and the amount of pollutants emitted to the environment increases. The classical feeding strategy is labour intensive. Feeds are transported to the feeding area by a tractor-drawn feed dispenser, a loader (basic feeds) and/or trolleys (concentrates, minerals). The classical feeding strategy has the following disadvantages:

- instability of the population of rumen microbes reduces the efficiency of using nutrients, especially that of feed protein;
- the value of rumen pH fluctuates within a wide range;
- animals have a freedom to choose tastier feeds;
- using of liquid feeds (distillery wash, pulp) and some feed additives (bitter taste) is problematic;
- labour consuming.

Overhead rail feed delivery system

An overhead feed dispenser is applied mainly in tie stall barns for precise distribution of concentrates and mineral feeds. A feed dispenser is programmable and according to technical properties, it can be equipped with several containers and measuring hoppers allowing dispensing feed according to necessity. The main disadvantage is high cost.

Total mixed ration (TMR) or poly-component mono-feed or mixer feed

The technology of TMR is mainly applied in loose housing farming facilities. The feeds are weighed, chopped (silage, hay, straw) and mixed thoroughly. The cows are offered the mixture of feeds. TMR mixers may be stationary or mobile. If stationary TMR technology is used, the feeds are weighed and blended in the feed centre. TMR is transported to the feeding area with a feed dispenser. Mobile technology is more widely used. Chopping, blending, and distribution of feeds are carried out with one, usually a tractor-driven TMR mixer. The mixer is equipped with electronic scales which enable to dose the feeds precisely. A critical factor for the success of TMR feeding is grouping of cows by milk production levels or by lactation phase. Usually the herd is divided into four groups: cows of negative-, zero and positive energy balance, and a dry cow group. Advantages of TMR as compared to classical feeding are the following:

- increase in milk production and milk fat content;
- reduced feed costs;
- reduced incidence rate of metabolic diseases;
- stabile population of rumen microbes, minimal fluctuation of rumen pH;

- cows can do very little sorting for individual ration ingredients - feeds are consumed in correctly balanced rations;
- it allows for wider use of unpalatable feeds (feed additives);
- lower emissions of nutrients to the environment due to improved means to balance feed rations in accordance with the animals need;
- potential to reduce labour required for feeding.

Disadvantages of TMR:

- it requires a significant equipment investment;
- it creates a need to group cows;
- in some cases the already existing facilities must be modernized;
- diet formulation needs a lot of knowledge.

Automatic concentrate dispenser

Concentrate dispensers are used in loose housing barns usually with TMR or MR (partially mixed ration) technology. The aim of using automatic concentrate dispensers is precise and selected feeding (supplemental feeding) of concentrates and mineral feeds (feed additives). Prerequisite of using the automatic concentrate dispensers is the presence of automatic identification system of animals (transponders and responders). The use of automatic concentrate dispensers increases the cost of feeding technology.

1.4.3 Bottlenecks (barriers) – knowledge/advice/farm adaptation

First, knowledge on specific feeding strategies and means has to be established aiming to solve the challenging tasks and the launched learning has to be adopted into practice by advisory systems or education. Furthermore, there is a need for knowledge exchange between practical farmers, the advisory system, and research because mutual ownership and understanding is important to overcome some barriers.

2 General aspects

2.1 Feeding evaluation systems

The objective of any feed evaluation system for ruminants is to predict the supply of available nutrients from robust measurements which can be made in the laboratory yet which recognise the essential principles of rumen and post-rumen digestion. Currently in many European countries, the metabolisable protein (MP, PBV) system is used for describing of feeds protein content, feed ration formulation and protein requirements of animals. The metabolisable protein system distinguishes (1) organic N that is degraded in the rumen and which can be incorporated into microbial N to an extent that is determined by the supply of fermentable energy; (2) protein N which escapes degradation in the rumen (Webster, 1996).

In monogastric animals, diverse feed evaluation systems are used in different countries. Regarding phosphorus digestibility in feedstuffs, most countries use standard values that are included in the feed optimization programs. However, it is difficult to overview how the individual countries establish and work out the exchange rate between microbial phytase and feed phosphates so that the utilization of phosphorus can be maximized without jeopardizing the animals' performance and health (see 4.5 where newly developed exchange rates for pigs are presented based on Henriksen et al., 2013). The effect of different commercially available products has been studied in many experiments with different monogastric animals (pigs, chickens, layers, ducks, turkeys etc.). However, the results are not always similar and depend on a lot of factors like diet composition, presence of plant phytase, feeding method, experimental setup etc. A review is conducted based on a compilation of scientifically published papers (Henriksen et al., 2013). The overall results are shown in details in section 4.5.

Determination of protein digestibility was earlier mainly determined as faecal digestibility but now the ileal digestibility of proteins and amino acid is more prevalent to characterize the protein value of feedstuffs (NRC, 2012). The digestibility of crystalline amino acids is often defined to approximate 100%.

2.2 Feeding principles

Basic feeds for cattle, regardless of housing- and feeding technologies, are grass feeds: silage made from grasses and/or leguminous grasses, hay and pasture grass. Cereals (barley, oats, maize, wheat, rye), various oil meals and -cakes (rapeseed, sunflower, soybean etc.) are being used as protein or as energy feeds (concentrates). For feeding young cattle, milk feeds are used. In cattle diets, mineral feeds play an important role as a source of calcium, phosphorus, other macro- and microelements, and vitamins. Feed and rations have a large impact on the amount and chemical composition of excreta.

Feeding principles in monogastric animals are to compose a diet that fulfils the animal's physiological requirement at a given physiologic stage or age (phase feeding, see 2.3). Therefore, feed optimization programs are based on information on nutrient and energy concentrations in all relevant feedstuffs and at the same time the nutrient requirement of the particular animal category in question. Often, such feed optimization programs also include feedstuff prices that may be used to suggest a price relevant feed composition.

2.3 Phase feeding (pigs, poultry) and balanced feeding (cattle), according to the animal's need.

Cattle

Best available technology is feeding cattle diets consisting of high-quality feeds which content of nutritive factors that meet the physiological requirements of animals. Nutritive factors that must be considered in the diet are the following: dry matter, metabolisable energy, digestible and/or metabolisable protein, fibre (crude fibre and/or ADF, NDF), calcium and phosphorus. Evaluating protein metabolism as a potential source of environmental pollution (one of the main end-products of protein metabolism is ammonia volatilized from excreta), it is necessary to consider rumen protein balance and milk urea content. A cow's physiological requirement of nutrients is affected by its genetic production potential, age, body mass and stage of lactation. Routine determination of chemical composition of feeds in a laboratory is a prerequisite for feeding according to physiological requirements.

Physiological nutrient requirements of cattle per a year/period depend on the age, body weight, weight gain and genetic production level. Feed consumption for covering the physiological requirements is affected by the quality of feeds (nutrient concentration in feed, digestibility, edibility, tastiness etc.) and balance of a diet. Unbalanced diets and low quality feeds increase feed consumption as well as the amount of residues released to the environment (potential pollutants).

The amount of feeds covering the physiological requirement of an animal is variable. It mainly depends on plant species used and dry matter content. The lower the dry matter of the diet is, the higher is the total amount of feeds.

Usually cattle are fed basic feeds (hay, silage, straw etc.) *ad libitum*. Nutrient requirements of the animals can be met and diet balanced by varying the content and composition of concentrates.

Monogastric animals

In monogastric animals, the use of more than one compound feed during the growth period is very widespread and has resulted in a more precise feeding of the animals. However, the number of different compound feeds depends on practicalities like silos, feeding systems and pipelines. The use of several compound feeds adapted to the changes in nutrient requirement along the growth period of the animals is called phase feeding and if many different diets are used, it could be called multi-phase feeding. Many countries have their own feeding recommendations but the main principles are the same. A more precise feeding according to the animals' need will result in better phosphorus and nitrogen utilization and reduced excretion of nutrients. The use of either *ad libitum* or restricted feeding depends mainly on the animals' genotype, sex, age, and the farmer's management. In pigs, ad libitum feeding of finishing pigs may lead to lowered meat content which is often not wanted because consumers demand low-fat products.

2.4 Productivity, performance (growth, milk, eggs, reproduction etc.); breeding programs

Nutrients and energy provided by the feed are used for performance or for maintenance, and the most efficient use is achieved when the daily performance is big whereby the relative contribution to maintenance is low. Breeding programs aiming to increase performance and/or reduce the feed conversion ratio are widely used resulting in more efficient genotypes at herd level. A lowered feed conversion ratio will, all things being equal, result in improved utilization of all nutrients and energy as the intake is lower whereas the retention is the same. Thus, modern breeding programs (genotype) may result in a phenotypic reaction leading to reductions in excretion.

2.5 Diet preparation

For dairy cattle with high milk yield is important to guarantee maximum dry matter intake and balanced concentration of nutrients in dry matter. For balanced and efficient feeding, it is insufficient to only use roughages. Average roughage and concentrates ratio (dry matter basis) in case-study farms (available only Swedish and Estonian data) varies 48-58% and 42-52% respectively (Sindhöj and Rodhe, 2013). Usually feed rations for cows with higher milk productions contain more concentrates. The roughage to concentrate ratio also depends on the lactation stage of animal. In the beginning of the lactation (negative energy balance) feed ration is more concentrated compared with mid lactation or dry period. Table 2.5.1 presents typical ration for cows (Estonian example) in the beginning of lactation (milk production 32.0 kg/day; body weight 650 kg; TMR).

Table 2.5.1 Daily feed ration for the cow in the beginning of lactation

Component	DM kg	Protein g	Metabolisable protein g	Protein balance value (PBV) g	Metabolisable energy MJ	Phosphorus g
Grass silage 1	5.0	650	376	325	47.0	14.6
Grass silage 2	2.5	260	174	-37	21.5	7.8
Barley	2.8	299	283	-165	36.2	10.7
Corn	2.2	189	261	-232	31.0	3.7
Rapeseed cake	1.5	563	226	216	20.4	18.0
Wheat	2.1	278	220	-85	29.0	9.0
Soybean cake	1.5	791	294	300	21.0	11.0
Mineral feed	0.2					8.0
NaCl	0.1					
$CaCO_3$	0.1					
Total	18.1	3030	1833	321	206.2	83.2
Roughages concentrates ratio		42:58				

3 Nitrogen

3.1 Monogastric animals (pigs, poultry) – specific challenges

First of all, specific knowledge on the age/physiological dependent nutrient requirement is needed and research and development are also necessary to establish knowledge on how to improve the nutrients use in feedstuffs and compound diets. Another major obstacle for improving nitrogen utilization is that the amino acid profiles of most feedstuffs of plant origin are not very appropriate for the requested profile for growth in pigs and poultry. This may, however, be partly overcome with the use of crystalline amino acids but at present only some of the essential amino acids are available in crystalline form (Table 1.2.3).

3.2 Ruminants (cattle) – specific challenges

Nutritional measures have multiple effects on N digestion, N excretion and excreta characteristics.

Feeding less (digestible) protein without affecting milk yield leads to less N excretion with urine. This may be achieved with less protein in dietary dry matter or less digestible protein. Many investigations demonstrated that both measures are highly effective to reduce urine N (Vérité et al., 2000). Furthermore, reduction in urinary excretion of N results in less ammonia emission (Castillo et al., 2000).

Lowering rumen protein balance. Model calculations indicate that more optimal use can be made of the capacity of recycling of urea from blood to rumen. A reduction to zero rumen N balance (N available from microbial N synthesis – microbial N synthesized) did not negatively affect microbial growth efficiency as often presumed. This omission results in 10 % less urine N, and a similar reduction in NH_3 emission.

Stimulating hindgut fermentation. Increasing dry matter intake and milk yield increases the efficiency of N utilization, reduces rumen digestibility (lower pH, faster passage) and stimulates fermentation in the hindgut. Also feeding specific by-products or more resistant starch-sources may shift fermentation of organic matter from rumen to hindgut. At a maximum, this leads to slightly more than 10 % reduction in urine N and hence in NH_3 emission.

Excreta volume and acidity. Although an increased urine volume decreases urea concentration, it will be accompanied by a higher frequency of urination as well and involves a more frequent refreshment of urine on floors and the manure top layer. This effect partly compensates the potential diminishing effect of reduced urea concentrations on NH_3 emission. Acidification of excreta reduces NH_3 emission as well. Urine acidity is more sensitive for salts additions to diets already low in cation content and pH values may approach 7 then. Faeces can be acidified to some extent by nutritional measures (hindgut fermentation) and reported pH values range from more than 7 to less than 6, probably depending on source and technological treatment of starch-supplements (Bannink, Reijs and Dijkstra, 2007).

3.3 Feedstuffs

The protein (nitrogen) content of forages is quite low. Nitrogen content and type (protein- or non protein N) of forages depends on the stage of maturity of plants, fertilization level and the species. Legumes generally contain more nitrogen than grasses. Table 3.3.1 presents average nitrogen content in some roughage's (Estonian tables of chemical composition and feeding values of feedstuffs, 2004).

Table 3.3.1. Average nitrogen content in some roughages

Roughage	DM, %	Nitrogen, g/kg DM
Grass hay (beginning of vegetation)	83	20.0
Legumes hay (beginning of vegetation)	83	24.8
Grass silage (beginning of vegetation)	35	25.1
Grass silage (middle of vegetation)	35	16.0
Legumes silage (beginning of vegetation)	35	27.7
Legumes silage (middle of vegetation)	35	21.1

The protein (nitrogen) content in cereals (Table 3.3.2) is moderate or also low, but high in oilseed meals and cakes.

Table 3.3.2. Average nitrogen content in some cereals, oilseed meals and oilseed cakes

Cereal	DM, %	Nitrogen, g/kg DM
Barley	86	20.0
Wheat	86	23.4
Oat	86	20.3
Corn	86	15.2
Rapeseed meal	88	36.0
Rapeseed cake	90	57.7
Soybean cake	88	80.0

3.4 Enzymes

Some studies have dealt with the effect of addition of enzymes to improve the digestibility of protein and thus amino acids in diets for monogastric animals. However, the effects of enzymes like protease, xylanase etc. are not uniform and most reports reveal only minor effects (Selle et al., 2000; Cowieson et al., 2009).

3.5 Dry vs. liquid feeding systems (pigs, poultry)

Liquid feeding systems that are more and more used in animal production have shown potential to increase the digestibility of nitrogen (Lyberg et al., 2006; Poulsen et al., in manuscript) but more studies are needed to define more precisely the effect that could be expected under practical farming conditions.

4 Phosphorus

Phosphorus is the second most abundant mineral in the animal body and about 80% is found in the bones and teeth. Phosphorus is required for the formation of the organic bone matrix as well as the mineralization of that matrix. The 20% of phosphorus not present in the skeletal tissues is widely distributed in the fluids and soft tissues of the body, where it serves a range of essential functions. In ruminants, the requirements of the rumen and caecocolonic microflora are also important, and microbial protein synthesis may be impaired on low-phosphorus diets (Petri et al., 1989).

4.1 Monogastric animals (pigs, poultry) – specific challenges

As mentioned, phosphorus is an essential mineral. However, monogastric animals cannot digest the plant based phytate phosphorus which is the most abundant phosphorus complex in cereals. Since compound feeds are based on plant feedstuffs, this is a serious hindrance for improvingphosphorus utilization. Another critical point is that not all feeding recommendations are expressed in terms of "digestible phosphorus" for all animal categories or for physiological relevant stages. This is needed for increasing the use of phase feeding. Another general drawback is that there may be huge differences in the results form chemical analyses of feedstuffs, compound feed, faeces, urine etc. depending on which chemical method is used (Hansen-Møller et al., 2007). This may result in non-comparable results obtained for scientific as well as practical use. This aspect is important to address within as well as between countries and may result in overfeeding as well as deficient phosphorus feeding (Hansen-Møller et al., 2007). These analytical problems may result in different recommendations between countries.

4.2 Ruminants (dairy cows) – specific challenges

Phosphorus availability from feeds is very variable, depending on the age of animal, physiological stage (lactation or dry) and also from calcium, magnesium, manganese, iron, aluminium and potassium concentration in feed ration, pH in digestive tract etc. Average phosphorus absorbing level from feeds for young cattle is 55-90% and 40-50% for adult cattle respectively. Investigation in last decades indicates that phosphorus absorption is now higher. Average phosphorus absorption level in NRC (Nutrient Requirements of Dairy cattle) (2001) is now 58-60%. Results from a number of short- and long term investigations indicated that phosphorus concentration over 4.2 g/kg DM of TMR is not efficient (also from the point of view of environmental pollution). In some countries phosphorus requirements for cattle have been reduced, NRC (2001) 3.5-3.8 g/kg DM, Swedish normative 2,8-3,2 g/kg DM, but not for example in Estonia 4.5-5.0 g/kg DM (Sikk, 2007).

4.3 Feedstuffs

Dairy cows. The phosphorus status of forages varies widely and is influenced primarily by the phosphorus status of the soil, the stage of maturity of the plant and the climate. Legumes generally contain more phosphorus than grasses (3.2 vs. 2.7 g P kg DM) (Minson, 1990). Recent evidence suggests that a high proportion (0.64-0.86) of the phosphorus in dry or fresh forages is absorbable in digestive tract of cattle (Ternouth, 1989; Ternouth et al., 1990, 1996) and sheep (Field et al, 1984). Table 4.3.1 presents average phosphorus content in roughage (Estonian tables of chemical composition and feeding values of feedstuffs, 2004).

Table 4.3.1. Average phosphorus content in some roughages

Roughage	DM, %	Phosphorus, g/kg DM
Grass hay (beginning of vegetation)	83	2.7
Legumes hay (beginning of vegetation)	83	2.7
Grass silage (beginning of vegetation)	35	3.2
Grass silage (middle of vegetation)	35	2.6
Legumes silage (beginning of vegetation)	35	3.0
Legumes silage (middle of vegetation)	35	2.3

Cereals contain relatively uniform and apparently adequate phosphorus concentrations (2.7-4.3 g P kg DM) and vegetable protein sources contain even more phosphorus (5-12 g P kg DM). Most of this (50-80%) is present as phytate P, which is well utilized by ruminants. Highly absorbable P (78-81%) have been reported for two cereal and three vegetable protein sources for sheep (Field et al., 1984). Phosphorus deficiency should therefore never arise in ruminants given significant amounts of concentrate feeds. Table 4.3.2 presents average phosphorus content in some cereals and oilseed cakes and table 4.3.3 the relative content of phytate P (Estonian tables of chemical composition and feeding values of feedstuffs, 2004).

Table 4.3.2. Average phosphorus content in some cereals and oilseed cakes

Cereal or cake	DM, %	Phosphorus, g/kg DM
Barley	86	4.1
Wheat	86	3.8
Oat	86	3.8
Corn	86	3.1
Rapeseed cake	90	10.5
Soybean cake	88	7.3

Table 4.3.3. Content of total phosphorus and phytate-phosphorus in selected plant feedstuff

Feedstuffs	Total P, %	Phytate-P, %
Maize	0.28	0.19
Wheat	0.33	0.22
Barley	0.37	0.22
Triticale	0.37	0.25
Rye	0.36	0.22
Sorghum	0.27	0.19
Wheat bran	1.16	0.97
Rice bran	1.71	1.10
Soybean meal	0.61	0.32
Peanut meal	0.68	0.32
Rapeseed meal	1.12	0.40
Sunflower meal	1.00	0.44
Peas	0.38	0.17

Pigs and poultry. Compound feed for monogastric animals is mainly based on cereals and plant protein sources. These feedstuffs contain different amounts of P which is to a large extent present as phytate P although the relative presence varies between feedstuffs (Table 4.3.4). Furthermore, enzyme phytase displays different activities in the different feedstuffs which may affect the P digestibility of the feedstuffs but also the P digestibility of the compound feed. Table 4.3.4 shows that rye is superior to all other cereals and corn and oats possess very limited or no phytase activity. In addition to this, there is often variation between cultivars within cereal species which may interfere with the overall anticipated effect of phytase (see 4.5). The absence of phytase activity in protein feedstuffs like soybean and rapeseed meal is due to the processing of the seeds (oil extraction) where phytase may be inactivated during the processes. Heat-treatment (above 50 to 60^0 C) is known also to completely or partially inactivate phytase activity of cereals. This has main effects on the overall digestibility and utilization of phytate P (see 4.5).

Table 4.3.4. Total phosphorus and phytate phosphorus concentration and phytase activity in feedstuffs[1] (Eeckout and de Pape, 1994)

Feedstuff	g P/kg	g phytate P/kg	Phytate P, %	Phytase, FTU/kg[2]
Wheat	3.3	2.2	67	1193 (915-1581)
Barley	3.7	2.2	60	582 (408-882)
Triticale	3.7	2.5	67	1688 (1475-2039)
Rye	3.6	2.2	61	5130 (4132-6127)
Oat	3.6	2.1	59	42 (0-108)
Corn	2.8	1.9	68	15 (0-46)
Wheat bran	11.6	9.7	84	2957 (1180-5208)
Soybean meal	6.6	3.5	53	40 (0-120)
Rapeseed meal	11.2	4.0	36	16 (0-36)

[1] Cereals are not heat treated.
[2] 1 FTU corresponds to the amount of enzyme that liberates 1 µmol inorganic orthophosphate per minit from 0.0051 mol/L sodium phytate at pH 5.5 and 37°C

Table 4.3.4 clearly demonstrates that it's necessary to carry out chemical analysis locally to be able to evaluate the local/regional cereal and feedstuff P contents and phytase activity in order to be able to optimize the feed composition to fulfil the animals' requirement and at the same time not to feed excessive amounts of dietary P (see also 4.5). If the animals are fed deficient P, they will suffer from P deficiency resulting in low productivity and health problems. Contrarily, excess dietary P results in too large P excretions.

4.4 Phosphorus requirement and need for feed phosphates

4.4.1 Cattle

Phosphorus requirements for cattle NRC (1984) recommendations ranging from 2.2 to 4.3 g P kg DM for calves and 1.9 to 3.9 g P kg DM for lactating cows. Requirements are greatest for young, rapidly growing calves and decline markedly with age. Table 4.4.1.1 presents phosphorus requirements for dairy cows in different lactation stages (Estonian normative) (Sikk, 2007).

Table 4.4.1.1. Phosphorus requirements (g/kg DM) for dairy cows in different lactation stages

	Cows after calving	Lactating cows, milk production kg/day			Dry cows	Pre calving period
		15	30	40		
Phosphorus, g	4.5	3.9	4.1	4.7	3.0	6.0

The absorption of phosphorus in mineral feeds for cattle varies widely. Mineral phosphates with high availability should be preferred if mineral phosphate supplementation is needed. Table 4.4.1.2 presents phosphorus content and availability in some mineral feeds (NRC, 2001) and it is clear, that sodium phosphate has the highest availability.

Table 4.4.1.2. Phosphorus content and availability in some mineral feeds

Mineral feed	DM %	P g/kg	P availability %
Sodiumphosphate $NaH_2PO_4 \times H_2O$	97	225	90
Monocalciumphosphate $Ca(H_2PO_4)_2$	97	216	80
Dicalciumphosphate $CaHPO_4$	97	193	75
Defluorinated phosphate	100	180	65

4.4.2 Pigs

The phosphorus requirement of pigs is transferred into practical recommendations which often are country or regional defined. In principle, the recommendations encompass the experimentally determined requirement and a safety margin taking deviations in practice into account. Formerly, the safety margin was rather large due to lack of knowledge. However, the safety margin is getting smaller due to improved knowledge. The current Danish phosphorus recommendations are shown in Table 4.4.2.1. Previously, the recommendations were based on total P but since the 1990'es, the recommendations are gradually based on digestible P in most countries.

Table 4.4.2.1 Current phosphorus (P) recommendations in Denmark (Tybirk et al., 2013)

			Recommended total P/kg[1]	
	Digestible P, g/FEs	Calcium, g/FEs	At 500 FTU/FEs	At 1000 FTU/FEs
Sows:				
Pregnant	2.0	6.5	3.8	3.4
Lactating	2.7	7.5	4.8	4.4
Piglets:				
9-30 kg	3.1	8.0	5.2	4.9
Growing-finishing:				
30-45 kg	2.6	7.0	4.4	4.1
45-105 kg	2.4	6.5	4.4	4.1

[1] Only recommended levels. The optimization programs are based on digestible phosphorus

Most of the phosphorus in plant feedstuffs is in the form of phytate P, which used to be largely unavailable for pigs and poultry. Therefore, mineral P (feed phosphates) was supplemented to fulfil the animals' requirement. Until 1 to 2 decades ago, the availability (digestibility) of the different sources of P was not considered wherefore the safety margin (see 4.4.2) did encompass all types from the poorest to the best available P feed phosphate sources. Now, the P availability of the different sources should be taken into account when formulating feed using feed optimization programmes. Experiments have been conducted to determine the digestibility of mineral P and Table 4.4.2.2 shows the values that are adapted into the Danish recommendations (Poulsen, 2007).

Table 4.4.2.2 Digestibility of P in different feed phosphates fed to pigs (adapted from Poulsen, 2007)

Source	Content in source, %		Phosphorus digestibility, %
	Phosphorus	Calcium	
Di-calcium phosphate	17	23	53
Di-calcium phosphate	18	25	52
Di-calcium phosphate	17	25	51
Mono-calcium phosphate	23	17	68
Mono-calcium phosphate	17	20	65
Mono-calcium phosphate	18	22	65
Ca-Na-phosphate	18	31	50
Di-calcium phosphate	19	25	59
Mono-calcium phosphate	20	15	64
Mono-sodium phosphate	24	0	79
Mono-dicalcium phosphate	21	20	72
Monosodium phosphate	24	0	80
Mono-calcium phosphate	19	17	71
Mono-calcium phosphate	13	19	75

Table 4.4.2.2 shows that P digestibility depends on the type of feed phosphates and is only 50% available to the pig in the poorest sources whereas the digestibility is about 80% in the water soluble type (mono-sodium phosphate). At the same time, there is some variation in the obtained results among the same types, and in Denmark, the chosen strategy is to use mono-calcium phosphate (MCP) with a mean P digestibility of 67% when feed phosphate supplementation is needed. The use of feed phosphate in Danish animal production was about 17.000 t (pure P) in 2000 but has decreased to about 11-12.000 t in 2011 due to that a tax on feed phosphate was introduced in 2004 stimulating the farmers and feedstuff companies to replace feed phosphates by phytase (4.5). However, this calls for appropriate exchange rates between microbial phytase and feed phosphates. This issue is handled more profoundly in the next section.

4.5 Microbial phytase and recommended equations for practical use

Figure 1.2.2.1 shows the intact phytate molecule that contains 6 phosphate groups but the problem is that the phytate complex is hard to digest for especially the monogastric animals. This is a serious barrier for improvements in P utilization as up to 75% of P in compound feed is as phytate because phytate is the main P storage form in feedstuffs of seed origin (cereals and protein sources (soybean, rape) (Figure 1.2.2.1). However as pointed out in sections 1.2.2, 1.2.3, and 4.3, phytase of plant or microbial origin has the potential to release of phosphate from the phytate complex rendering P available for absorption. Since the early 1990's, microbial phytase has been intensively studied in numerous experiments conducted to verify the efficiency and potential when used under different conditions (animal category, feed composition and processing, feeding strategy etc.). This has resulted in various and not always uniform effects which may and has given rise to mistakes and problems when microbial phytase was applied in practical feeding. Despite this, microbial phytase is now widely used in conventional pig and poultry feed but it is recognized that microbial phytase could in many occasions be used more effective to improve P utilization and lessen the excretion of P to the manure.

Since the appearance of the first version or type of commercial phytase in the 1990's, many different types of phytase has been developed and many different types are now commercially available and applicable in feeding practice. A review study was conducted to compile all published studies that examined the effect of microbial phytase on P digestibility using a basic diet with or with phytase supplementation in the period from 1991 to 2012 (Henriksen et al., 2013). The main outcome from the review study is presented in this section. Table 4.5.1 presents the list of phytases that have been used in published studies on phytase in pig production together with the year they were approved and their classification (of fungal or bacterial derived; which phosphate position of the phytate molecule they initiate; number of observations published in international papers). The stereospecificity of phytate (also called myo-inositol hexakisphosphate) is detailed discussed by e.g. Greiner et al., 2000.

Table 4.5.1 List of phytases used in pig experiments published from 1991 to winter 2012/13 (Henriksen et al., 2013)

Phytase product[a]	Year of approval	Phytase type	Obs[b]
Fungal-derived:			178
Allzyme	1998	Not known	13
Finase	1998	3-phytase	20
Ronozyme	2007	6-phytase	16
Natuphos	2007	3-phytase	113
Bacterial-derived:			46
Optiphos	2005	6-phytase	19
Phyzyme	2007	6-phytase	10
Quantum-Q1	2008	6-phytase	8

[a]Information from: www.eur-lex.europa.eu, www.alltech.com and www.novonordisk.com (Assessed 15/1 2013).
[b]Obs = Observations.

Cereal type – low or rich in intrinsic phytase. The review confirms that a variety of factors influencing the effect of microbial phytase could be detected. One important factor is which cereals are used for the basic diet, corn (low in phytase activity) or wheat/barley (high in phytase activity). In corn based diets, the net increase in digestible P content was generally higher compared with barley/wheat based diets (0.63 g vs. 0.55 g digestible P/kg DM) but the resulting P digestibility was very different in corn compared with wheat/barley based diets (47 vs. 57%). These results show that it is important to take the basic diet composition into account when evaluating the potential of microbial phytase supplementation. In general, the potential is higher in corn than in wheat/barley based diets.

Heat treatment or no heat treatment. Another issue to address is if the diets are heat treated during processing or not. This is due to that the intrinsic phytase (in wheat, barley etc.) will be inactivated during heat processing. The situation with heat treatment corresponds to farmers getting their compound feed from feedstuff companies whereas non-heat treatment corresponds to on-farm production of the feed where the cereals are not heat treated causing no loss in intrinsic phytase activity. Table 4.5.2 shows that the effect of microbial phytase clearly was dose dependent. In general, the lower dose the bigger difference resulting in differences between 0.32 (lowest dose) to 0.11 (highest dose) g digestible P/kg DM. Equations for the prediction of the increase in digestible P (g/kg DM) were fitted based on all published results and given for both heat treated and non-heat treated feed. These equations can be used for evaluation of the expected effect to be obtained in practical farm situations in relation to the actual dose to be used.

Table 4.5.2. The predicted increase in digestible P content (g/kg DM) for non-heat-treated and heat-treated diets at different doses of microbial phytase (FTU/ kg diet) (Henriksen et al., 2013).

	Microbial phytase, FTU/kg diet			
	250	500	750	1000
Non-heat-treated[a]	0.35	0.54	0.65	0.73
Heat-treated[b]	0.67	0.75	0.80	0.84

[a] $y = 0.2745 \times \log_e(x) - 1.1701$, where y is the predicted increase in digestible P (g/kg DM) and x is microbial phytase (FTU/kg diet), equations fitted for phytase dosages ≤ 1,000 FTU/kg diet.
[b] $y = 0.1197 \times \log_e(x) + 0.0103$, where y is the predicted increase in digestible P (g/kg DM) and x is microbial phytase (FTU/kg diet), equations fitted for phytase dosages ≤ 1,000 FTU/kg diet.

Feed phosphate. Generally, if feed phosphate supplementation is used, the effect of additional microbial phytase supplementation will be reduced compared with no use of feed phosphates. All in all, the effect is reduced by 10 to 40% depending on phytase dose with the greatest effect at low microbial phytase dose (Henriksen et al., 2013).

Fungal or bacterial phytase. The first commercially available phytases were fungal derived but later, phytases were also produced using bacteria. The review study revealed not much difference between the bacterial and fungal derived products (defined in Table 4.5.1), in general, the P digestibility was about 50% after inclusion of both types of phytases (Henriksen et al., 2013).

Exchange rate between inorganic feed phosphates and microbial phytases. Aiming at improving the P utilization by use of microbial phytases, it is neccessary at the same time to reduce P input. The easiest way is to remove the inorganic feed phosphates and increase the use of the feedborne P by inclusion of microbial phytase. The reason is, that phytase will increase the digestibility of the phytate P whereby the need for extra feed phosphate (inorganic mineral P) will be reduced or even eliminated. This will, however, require that the establishment of a safe exchange rate between microbial phytase and feed phosphate P. Based on the litterature review such equations was established (Henriksen et al., 2013) for feed with low or high intrinsic phytase activity in a dose dependent way (Table 4.5.3).

4.5.3 The predicted increase in digestible P content (g/kg DM) when microbial phytase are added to diets with low (corn based) or high (wheat/barley based) intrinsic phytase activity (Henriksen et al., 2013). The equations are presented by footnotes.

Intrinsic phytase	Supplemented microbial phytase, FTU/kg DM					
	250	500	750	1000	1250	1500
Low[1]	0.40	0.60	0.71	0.79	0.85	0.91
High[2]	0.29	0.47	0.58	0.65	0.71	0.76

[1] Equation: $y(\text{corn}) = 0.2854 \times \log_e(x) - 1.2014$, $R^2 = 0.28$, x = microbial phytase (FTU/kg diet)
[2] Equation: $y(\text{wheat/barley}) = 0.2646 \times \log_e(x) - 1.1753$, $R^2 = 0.19$, x = microbial phytase (FTU/kg diet)

Table 4.5.3 shows that the predicted effect of microbial phytase supplementation is generally higher in feed that has a low intrinsic phytase activity compared with feed high in plant phytase activity. Furthermore, the increase in digestible P content is dose dependent in both cases (Henriksen et al., 2013). The predicted effect of different microbial phytase additions can be calculated by use of the equations in Table 4.5.3 to obtain indications for practical use if no specific information is available. However, it should be emphazised that the values are only to be used as guidelines and only for dry feeding systems.

For practical use, it is important to know if the different comercially available phytases (products) vary so that some products are more efficient than others. Table 4.5.4 shows results on the effectiveness of different current microbial phytases that are commercially available.

Table 4.5.4 Effects of different types of commercially available phytases on phosphorus (P) digestibility, % and increase in g digestible P compared to the basic diet (4.1 g total P and intrinsic plant phytase, 175 FTU/kg; dry feeding) (Poulsen et al., 2013)

	1	2	3	4	5
	Control, 0 FTU	Natuphos, 750 FTU	Phyzyme, 750 FTU	Ronozyme, 1500 FTU	Ron-HI, 1000 FTU
P digestibility, %	41	63	61	59	63
Digested P/kg feed	1.66	2.56	2.48	2.40	2.56
Increase in dige-sted P, g/kg feed	-	0.89	0.81	0.73	0.89

The P digestibility of the basic diet was 41% and addition of microbial phytase increased in all cases the P digestibility by about 20 percentage-units to 59 to 63% which are in agreement with the results obtained in the review (Henriksen et al., 2013). Table 4.5.4 also shows that the inclusion of phytase results in an overall content of up to 2.6 g digestible P which should be sufficient to fulfil the requirement for digestible P in finishing pigs (Table 4.4.2.1).

The review also clearly demonstrated that the P digestibility in dry feeding generally does not exceed about 65% even though very high doses of microbial phytase are applied (Henriksen et al., 2013). This was also confirmed in the conducted experiment with currently commercially available for practical farming (Table 4.5.4) where none of the phytase (also used in quite high inclusion rates) increased the digestiblity to above 65 % in dry feeding containing no feed phosphates (Poulsen et al., 2013). This means that often more than 35% of the dietary P will not be absorbed but will be excreted via the faeces. The reason for the rather low P digestibility is that P is absorbed in the proximal part of the small intestine and accordingly, the phosphate groups have to be released from phytate prior to the absorptive area of the small intestine (Blaabjerg et al., 2011). If the phosphate groups are released more distally in the gastrointestinal tract, they cannot be absorbed and will end up in the faeces and manure.

Recent studies have shown that one of the major bottlenecks for phytate degradation is the retention time of the feed in the stomach which is often very short. Generally, up to 30% of the feed has left the stomach within 1 h after feeding (Blaabjerg et al., 2010; 2011). Furthermore, studies have shown that the bottleneck for phytate degradation is the release of the first phosphate group. If this can be achieved, the remaining phosphate groups are easily dissolved (Blaabjerg et al., 2010; 2011). These observations are important for the understanding of the possibilities for improvements in the plantborn P, especially in dry feeding systems but also for the seeking for possible feeding means to improve P utilization.

4.6 Dry vs. liquid feeding systems (pigs, poultry)

The above mentioned review is based on published scientific results obtained by use of dry feeding systems. However, the use of liquid feeding systems is becoming more and more prevalent in modern pig production. This opens up for an increased degradation of phytate and thus release of phosphate P that could be absorbed and used by the pigs. Therefore, liquid feeding systems may induce a kind of "pre-digestion" as the enzymatic processes brought about by the phytases will start before the feed inters the mouth and stomach of the pigs. Recent results have shown that in some occasions, all phosphate groups may be released from phytate (Figure 1.2.2.1). However, the releasing process is dependent on time, temperature, pH etc. of the liquid feed (Lyberg et al., 2005; 2006; Blaabjerg et al., 2010; 2011).

In pig feeding and maybe also poultry feeding, the use of liquid feeding or soaking seems to be a promising approach than can be used as a tool for further improvements in P utilization whereby the P excretion can be lowered and the P content of manure can be reduced. This will, especially in farm animal dense areas, enable an overall improvement in soil P balance and thus reduce the risk of P loss due to leaching or erosion.

It should be emphasised that the use of liquid feeding systems or soaking of diets prior to feeding as a mean to degrade phytate releasing phosphate needs to be optimized and adapted to the farm situations as these may not directly be ideal in relation to temperature, time, pH etc. (Blaabjerg et al., 2011). The overall perspectives of the use of liquid feeding is that nutrients (phosphorus but also protein, amino acids and others) present in plant feedstuffs are made more available to pigs and poultry compared to dry feeding. This means that less feed phosphate supplementation is needed to fulfil the animals' requirement. Overall, this approach will lead to reduced excretion of phosphorus. The same is applies for protein and amino acids.

The use of liquid feeding in practical farming is now widespread but the exact prevalence is not known and will definitely vary between countries due to use of different feedstuffs and due to traditions and economic situation. Furthermore, some figures relate to total number of pigs raised and some guestimates are based on number of farms equipped with liquid feeding systems. As such, no absolute figures on occurrence can be given but our research indicates that more than 50% and in some areas up to 70% of pigs are raised on farms equipped with liquid feeding systems. Furthermore, all consultants expect that the use of liquid feeding systems will increase at the expense of dry feeding systems.

4.7 Available vs. total P

Phytate-phosphorus (Figure 1.2.2.1), which is normally present in plant feed materials), is not available to pigs and poultry as they lack the appropriate enzyme activity in their digestive tract. Due to that big amounts of non-digestible phosphorus are excreted, posing a great risk to environment. The digestibility of P can be improved (reducing its content in the diet and excreta) by using the following methods:

- Adding of the enzyme phytase (currently four phytase preparations are authorised as feed additives in the European Union (Directive 70/524/EEC).
- Increasing the availability of P in plant feed materials.
- Reducing the use of inorganic phosphates in feeds.
- Expressing the phosphorus requirement in terms of g digestible P/kg diet instead of g total P/kg diet.

5 Short summary

5.1 General

The increase in number and productivity of farm animals in the Baltic Sea Region has for decades increased the demand for import of feedstuff, especially protein sources like soy bean meal from other continents. Furthermore, mined phosphates are also introduced into the livestock sector. This import has resulted in an increase in manure nutrient content. In many animal dense areas this has led to a soil supply that is above the crop demand. However, increased focus on the environment and specifically the aquatic environment has been one of the main driving forces for improvements in nutrient utilization and derived reductions in excretions of phosphorus and nitrogen in farm animals.

Animals need protein and amino acids - containing nitrogen - for growth and production. In former days, amino acids could only be provided by the feedstuffs. Thus, the required dietary crude protein to fulfil the animals' requirement was very high resulting in a correspondingly low net utilization and large excretion of nitrogen. Phosphorus is also an essential nutrient for animals and an adequate supply to livestock is therefore important to ensure production and health. In the past, much effort was attributed to make sure that farm animals received sufficient phosphorus to satisfy their physiological requirement. The addition of mineral phosphate (feed phosphate) was introduced at those days and became widely used for decades because the digestibility of phosphorus in cereals and seeds was too low to fulfil their need. As a result, the animals no longer suffered from phosphorus deficiency but at the same time, the net utilization of phosphorus was low resulting in large excretion of phosphorus to the manure.

Changes in feeding and feeding methods provide tools for improvements in nutrient utilization contributing to or future reductions in the excretion of nutrients. A more efficient use of feed nutrients in livestock farming demands specific knowledge on nutrient concentration and quality of the feed expressed as e.g. the amino acid profile of crude protein. Regarding phosphorus, focus is on the phytate phosphorus content of plant feedstuffs and the presence and activity of the enzyme phytase that stimulates the degradation of phytate rendering phosphate available for absorption. When phytate is degraded and phosphates released and absorbed the need for imported feed phosphates is lowered. The overall aim is to reduce the import of mined feed phosphate and feedstuffs like soybean meal that contains a lot of protein and phosphorus. The largest single factor causing the environmental impact of animal husbandry in the Baltic Sea Region is correlated to the import of feedstuffs and thereby nutrients from other continents.

Improved feeding strategies are required to decrease the need for imported of feedstuffs like soybean meal and feed phosphates. Dietary crude protein can be replaced by industrially produced amino acids like lysine, methionine, threonine, and tryptophan which results in a lowered inclusion rate of soybean meal. At the same time, the increased use of microbial and plant phytase can diminish the need for feed phosphates, mainly in monogastric animals. More precise feeding strategies like phase feeding are important tools and recently, liquid feeding seems to be valuable to increase the digestibility of phosphorus and to some extent also protein by initiating the digestive processes before the feed is consumed by the animals.

Breeding for improvements in feed conversion rate, i.e. kg feed per kg gain or product is an important factor for enhanced nutrient and energy utilization and has been embedded in the overall breeding strategy and many countries. In general, the feed conversion rate should be as low as possible to reduce the excretion of nutrients like nitrogen and phosphorus.

Feed optimization programmes have been developed and are continuously updated along with obtained improved knowledge on nutrient requirements of the animals and on feedstuff quality and digestibility of nutrients.

A holistic approach regarding the utilization of nitrogen and phosphorus is needed and the feeding report presents feeding methods and strategies that affect the use and excretion of nitrogen and phosphorus in ruminants, pigs and poultry. Reductions in the use of imported feedstuffs are not only the key to improved nitrogen and phosphorus utilization but also for reductions in emissions of ammonia and greenhouse gasses.

5.2 Phosphorus

- Phosphorus has to be fed sufficient amounts to fulfil the animals' physiological requirement
- Feedstuffs provide phosphorus but grains and seeds contain up to 70-80% phytate phosphorus which is difficult to digest for monogastric animals as they don't produce phytase in the gastrointestinal tract.

- Feed phosphates are used as additive to make sure that the feed contains sufficient amounts of phosphorus.
- Phytase (enzyme) catalyses the degradation phytate rendering phosphate available for absorption.
- Cereals like barley, wheat, triticale, and rye but not corn and oat possess phytase but if the grains are heat-treated, phytase is often inactivated.
- Phytase is now produced microbial and commercially available in different variants.

5.3 Nitrogen

- Protein and the essential amino acids have to be provided by the feedstuffs to fulfil the animals' physiological requirement.
- The protein and amino acid content and quality of feedstuffs of plant origin do not match the animals' requirement and crude protein content has to be very high to match the need for the first limiting amino acids.
- Some of the essential limiting amino acids are available in crystalline form and can replace dietary protein in feed for monogastric animals.
- Rations optimized to fulfil the need for protein and amino acids have to be used for all livestock species and categories.

6 Conclusions

6.1 Phosphorus

- Differentiated P feeding recommendations according to the animals' physiological state should be given.
- Phase feeding e.g. differentiated feeding according requirement in pregnant or lactating sows (2-3 phases) and growing-finishing pigs (4-5 phases depending on the body weight at slaughter) should be used.
- P recommendations for monogastric animals should be based on "available or digestible phosphorus" and not "total phosphorus".
- Tables on mean phosphorus content (and variation) of all relevant feedstuffs should be established and updated regularly. Chemical analyses of feed batches or on farm produced feed are recommended.
- Phosphorus digestibility of all major feedstuffs should be established or adapted from foreign experiments and tables.

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- The knowledge on phosphorus contents and digestibility should be used in feed optimization programmes to optimize the diet composition to avoid phosphorus oversupply (environment) or undersupply (deficiency).
- Addition of microbial phytase should be used in monogastric feeding (specific dosage recommendations are given in the feeding report). Exception: when high phytase cereals are used.
- It's fundamental to remove feed phosphate (mineral), when microbial phytase is added.
- Heat-treatment inactivates phytase to a large extent and should be considered during the feed producing process which also should ensure a homogenous application of the added microbial.
- Liquid feeding systems improve phosphorus utilization and are an important tool to reduce phosphorus excretion in monogastric animals.
- Dairy cows fed contrite feeds should never suffer from phosphorus deficiency for which reason phosphorus supplements as feed phosphates should not (or seldom) be used.
- Phosphorus recommendations vary between countries and it is recommended that each country focus on the actual recommendations and compare to other countries to evaluate if the physiologically based recommendations can be lowered.

6.2 Nitrogen

- The animals do not require nitrogen but protein and amino acids that are provided by the feed.
- The actual requirement depends on the physiologic stage and productivity of the animals.
- The protein content and amino acid profile of the plant feedstuffs do not in particular match the animals' specific amino acid requirement.
- Soybean and other protein rich feedstuffs are imported the Baltic Sea Region as the regional production of protein rich feedstuffs is not large enough to sustain the need for dietary protein by the increasing livestock production.
- The order of limiting amino acids is lysine, methionine, threonine, tryptophan etc. in monogastric animals.
- Crystalline amino acids are commercially available and can replace crude protei n in monogastric animals resulting in reduced need for imported protein feedstuffs like soybean.
- Reduction of the rumen nitrogen balance to zero will assure optimal recycling of urea from blood to rumen and improve the nitrogen utilization
- The use of crystalline amino acids is currently not an option in ruminants.

- Liquid feeding systems also seem improve the digestibility of protein and amino acids to some extent in monogastric animals.
- Feeding recommendations on protein and amino acid vary between countries and it is recommended that each country focus on the actual recommendations and compare to other countries to evaluate if the physiologically based recommendations can be lowered.
- Feed optimization programmes and phase feeding should be used where the nutrient content and profile is adapted to the animals' specific need.

7 Feeding recommendations

Define specific feeding recommendations on phosphorus and protein and/or amino acids for the animals' different physiological phases (all animals).

Provide phosphorus, protein/amino acids in appropriate amounts via feeding to ensure production, health and welfare and avoid excessive amounts (all animals).

Analyse for contents of phosphorus and protein/amino acids in the feedstuffs that are used in the feeding of animals on the farms and keep the feedstuff tables updated on nutrient and energy contents (all animals).

Use the multiphase feeding concept, where the different phases are adapted to the animals' physiological requirement to reduce the intake and excretion of P and N (all animals).

Be aware of appropriate and homogenous mixing, especially when microbial phytase or other feed components like amino acids are added (all animals).

Lower the feed conversion ratio as much as possible through focus on genetic breed and farm management (all animals).

Use "digestible phosphorus" instead of "total phosphorus" to establish phosphorus recommendations (pigs and poultry).

Replace feed phosphates (mineral) by inclusion of microbial phytase in feeds for pigs and poultry.

Use the presented equations to get an expected effect of microbial phytase inclusion in pig feed.

Optimize the use of liquid feeding that may be used to reduce phosphorus and nitrogen excretion in pigs.

Reduce the necessity for inclusion of crude protein from protein sources (soybean, rapeseed etc.) by use of the commercially available crystalline essential amino acids (pigs and poultry) and thereby reduce the import of soybean and other protein rich feedstuffs into the Baltic region.

Use sources with high phosphorus digestibility whenever feed phosphate supply is needed (pigs, poultry and ruminants).

Ensure a balanced nutrient content and sufficient intake of dry matter in dairy cattle.

Use of significant amounts of concentrate feeds but without mineral phosphate assures that dairy cattle would never become deficient in phosphorus.

Feed less but more digestible protein to reduce nitrogen excretion.

Reduce the rumen nitrogen balance to zero which will assure optimal recycling of urea from blood to rumen and improve the nitrogen utilization.

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9 Annexes

9.1 Equations to be used in optimization programs with microbial phytase (pig feeding)

Equations to be used for prediction of the expected effect of inclusion of microbial phytase into pig diets that have a high content of plant phytase (non-heat treated) or a low plant phytase content (heat treated) feed (see Table 4.5.2). The increase is given in g digestible P/kg diet.

Non-heat treated (high plant phytase activity):

$y = 0.2745 \times \log_e(x) - 1.1701$, where y is the predicted increase in digestible P (g/kg DM) and x is microbial phytase (FTU/kg diet), equations fitted for phytase dosages ≤ 1,000 FTU/kg diet.

Heat treated (low plant phytase activity):

[b]$y = 0.1197 \times \log_e(x) + 0.0103$, where y is the predicted increase in digestible P (g/kg DM) and x is microbial phytase (FTU/kg diet), equations fitted for phytase dosages ≤ 1,000 FTU/kg diet.

Other equations for calculation of the effect of microbial phytase are given in chapter 4.5.

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This report in brief

Phosphorus and nitrogen (in the form of protein and amino acids) are both environmental factors and essential nutrients. An adequate supply of phosphorus, protein and amino acids is therefore important in order to ensure production and health of livestock. Hence, a balanced approach taking both the animals' requirements and the environment into consideration is required so that improvements in the environment do not result in poor health and production in the farm animals and vice versa.

The Baltic Manure project considers the whole chain from animals and feeding to manure treatment and use to soil status and eutrophication risks. The present report concerns the feeding part and presents the current feeding regimen and nutrient utilization and excretion in dairy cattle, pigs and poultry. Further, the report summarizes feeding methods to be considered in order to improve protein and phosphorus utilization and to reduce the excretion in intensive animal production.

The main conclusions are that the import of feedstuffs like soybean meal (protein rich) and mineral phosphates should be minimised and substituted by crystalline amino acids respectively phytase in feeds for pigs and poultry. In dairy cattle, feeding strategies like total mixed rations (TMR) that provide the sufficient amounts of nutrients are proposed.

This report was prepared as part of work package 3 on Innovative Technologies for Manure Handling.

About the project

The Baltic Sea Region is an area of intensive agricultural production. Animal manure is often considered to be a waste product and an environmental problem.

The long-term strategic objective of the project Baltic Manure is to change the general perception of manure from a waste product to a resource. This is done through research and by identifying inherent business opportunities with the proper manure handling technologies and policy framework.

To achieve this objective, three interconnected manure forums has been established with the focus areas of Knowledge, Policy and Business.

Read more at www.balticmanure.eu.

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