Default Phosphorus excretion factors of farm animals

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Wageningen UR Livestock Research and Central Veterinary Institute of Wageningen UR, both part of Stichting Dienst Landbouwkundig Onderzoek (DLO Foundation), together with the Department of Animal Sciences of Wageningen University comprises the Animal Sciences Group of Wageningen UR (University & Research centre).

ISO 9001 certification by DNV emphasizes our quality level. All our research projects are subject to the General Conditions of the Animal Sciences Group, which have been filed with the District Court Zwolle.

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Default Phosphorus excretion factors of farm animals

Task 6

Summary

The following conclusions can be drawn from this literature review.

- Phosphorus, that is not available for the animal, cannot be used for metabolic processes and will be excreted by the faeces.
- The available phosphorus requirement of livestock animals depends on their maintenance requirements and their production levels in terms of body weight gain, milk production, egg production or progeny production.
- The amount of consumed phosphorus that is not deposited in meat, milk, egg, or progeny will be excreted by the faeces and urine.
- Phosphorus excretion can be reduced by:
    - precisely adjusting the available P supply on the P requirements of the animals, e.g. by phase feeding
    - reducing the dietary unavailable phosphorus content, e.g. by adding (more) phytase to the diet
    - selecting dietary ingredients with a high available P content
    - improving the P availability of ingredients, e.g. by acidification or soaking in water
    - increasing nutrient density of the diet.

Moreover, default P excretion factors for different categories of livestock are provided.

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1 Introduction

This task aims to develop default Phosphorus (P)-excretion factors as function of animal type, and in line with the methodology proposed in Task 5, to be used by countries that do not have all data required for the proposed methodology in Task 5.
P-excretion of an animal is the result of P intake minus P retention. An animal requires P for maintenance and for production (e.g. milk, meat, progeny). If the level of milk production of a dairy cow, or the growth rate of a pig increases, dietary P supply should increase as well to cover the higher P demand. Part of this additional P-intake is retained in the animal, whereas the remaining part is excreted. This report describes the factors that are involved in P excretion.
Firstly, an in-depth literature review and desk study has been carried out on the P retention and excretion, as a function of animal category, feed ration and management, the digestibility of the P in animal feed, the role of phytase enzyme addition and animal productivity.
Secondly, the common approaches and methodologies for P excretion coefficients has been identified and summarized in detail for the main animal categories. Common building block are identified and described, based in part on the in-depth literature review.
Thirdly, we have analysed the practical feasibility of the building block approach for different animal categories.
The default P excretion factors are determined by averaging the available P excretion factors of the individual EU countries.

2 2 Building blocks relevant for phosphorus excretion.

The phosphorus (P) excretion of livestock animals is the result of the amount of P consumed by the animal minus the amount of P retained in animal products, e.g. in progeny, milk, meat or egg. The building blocks, that are related to phosphorus excretion, are shown in Figure 1. The factors that are influencing the phosphorus excretion are reviewed below. These building blocks are also discussed in Chapter 3 of Task 2.

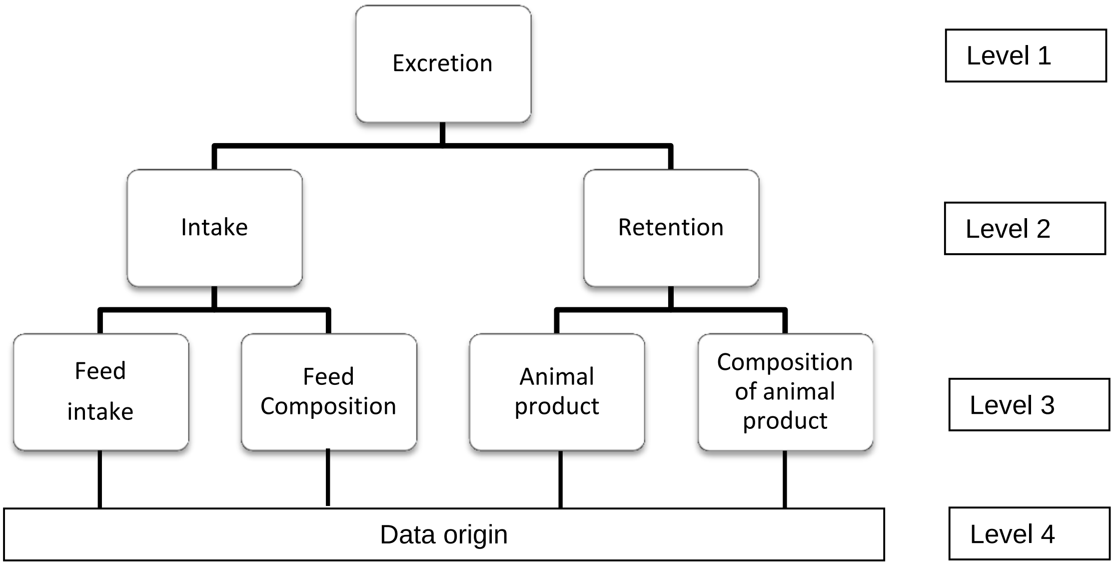

Figure 1 Factors affecting phosphorus excretion in livestock animals

Level 1 expresses the P excretion per animal, which is calculated as: P intake (kg/year) – P retention (kg/year). The P intake and P retention are calculated at Level 2:

- P intake
    - Feed intake per animal (kg product or kg dry matter per year)
    - Feed composition (g P per kg product or kg dry matter per feed)
- P retention
    - Growth, reproduction, milk, eggs and wool per animal (kg animal product)
    - Composition of growth, reproduction, milk, eggs and wool (g N and g P per kg animal product)

For calculation of the building blocks at Level 2, the data of Level 3 are required.

- Feed intake per animal or per animal category
- Feed composition per animal category

P intake is calculated as: Feed intake (kg/year) x Feed composition (P content /kg)

The P-retention is calculated as: animal production (kg/year) x composition of animal production (kg N or P/kg). These values are derived from Level 3.

Data origin (see level 4) for feed intake may have different sources:

- Defaults from common literature
- Specific defaults from country or region specific feed tables
- Calculated feed intake derived from registered animal production and feed requirements
- Annual registered feed intake
    - Country
    - Region
    - Farm
    - Animal

        - Individual
        - Category
        - Species

Data origin (see level 4) for feed composition may have different sources:
- Defaults from common literature
- Specific defaults from country or region specific feed tables
- Annual analyses of feeds and roughages

Data origin (see level 4) for animal production may have different sources:
- Defaults from common literature
- Specific defaults from country or region specific data bases
- Annual registered animal production
    - Country
    - Region
    - Farm
    - Animal
        - Individual
        - Category
        - Species

Data origin (see level 4) for animal composition may have different sources:
- Defaults from common literature
- Specific defaults from country or region specific experiments.

Chapter 3 provides more details regarding the data for filling these building blocks.

3 Phosphorus requirement and intake

3.1 P-requirement and intake in dairy cattle

The P-requirement of dairy cattle is determined by four factors, which are related to age and production stage (COMV, 2005):

1. Maintenance and endogenous losses
2. Milk production
3. Gestation
4. Body weight gain (heifer, cow in second lactation).

The net P-requirements for dairy cattle according to two authoritative systems, the Dutch (COMV, 2005) as well as to the American (NRC, 2001) system is summarized in Table 1. The American system is taken P losses by urine into account, whereas the Dutch approach assumed that urinary P losses are negligible. The Dutch system assumes a P-content of 1.0 g/kg milk with a standard deviation of 0.1 g/kg milk, and the American system assumes a P-content of 0.9 g/kg milk (Table 1). This difference is partly related to the milk protein content, resulting in a higher P-content with an increasing protein content. Moreover, the genetic background of the cow, as well as other dietary factors are influencing the milk P content (Van Krimpen et al., 2012).

Figure 1 shows the net P-requirement of Holstein dairy cattle during the gestation period, based on work of House and Bell (1993). They investigated in Holstein cows the mineral composition of foetuses with a gestation length that ranged from 190 to 270 d. Based on their results, the net P-requirement of Holstein cows during gestation from d190 onwards can be calculated with the following equation (NRC, 2001):

$$\text{Net P-requirement gestation} = 0.02743 \times e^{((0.05527 - 0.000075 \times d) \times d)} - 0.02743 \times e^{((0.05527 - 0.000075 \times (d-1)) \times (d-1))}$$

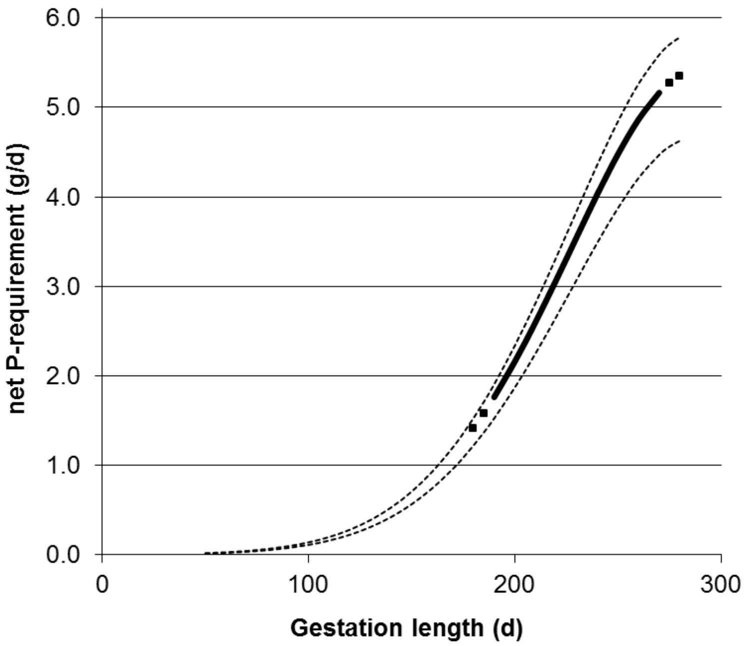

Figure 1 Net P-requirement of Holstein dairy cows during gestation, for delivering a calf of 46 kg. The under and upper dotted lines predict the P-requirement in case of calves with a birth weight of 40 and 50 kg, respectively

The amount of P that have to be added to the diet during the first 190 d of the gestation period is assumed to be negligible. (NRC, 2001). The solid line in Figure 1 shows the additional P-requirement of a cow that will give birth to a calf with a birth weight of 46 kg during d190 to d280 of the gestation period. The equation of House and Bell (1993) is extrapolated to the gestation period of d50 to d280, where the under and upper dotted lines predict the P-requirement in case of calves with a birth weight of 40 and 50 kg, respectively. Thus, the net P-requirement at the end of the gestation period will range between 4.6 and 5.8 g/d. In case of a twin pregnancy with a birth weight of 40 kg per calf, the net P-requirement is estimated to be 9 g/d at the end of the gestation period.

The net P-requirement for body weight gain of dairy cattle is based on the estimated body weight gain and on the P-retention in the body, and can be calculated by use of the following equation (AFRC, 1991):

Net P-requirement for body weight gain = $1,2 + (4.635 \times EAW^{0.22} \times CLW^{-0,22})$

in which EAW = expected adult weight (kg), and CW = current live weight (kg).

Table 1 Net P-requirement of dairy cattle according to the Dutch (COMV, 2005) and the American standard (NRC, 2001).

	COMV (2005)		**NRC (2001)**
	Gestation	***Lactation***	
Maintenance			
Losses by manure (g/kg dm intake)	1.04	0.81	1.00
Losses by urine (g/kg LW)	0	0	0.002
Gestation (g/d)			
8 to 3 wk before calving	4.1	4.1	4.1
3 to 0 wk before calving	5.1	5.1	5.1
Milk (g/kg)	-	1.0	0.9
Growth (g/kg growth)	$1.2 + (4.635xEAW^{0.22}xCLW^{-0.22})$		$1.2 + (4.635xEAW^{0.22}xCLW^{-0.22})$

dm = dry matter; EAW = expected adult weight; CLW = current live weight

Gross P-requirement dairy cattle

Based on the values of Table 1, the daily net P-requirement of dairy cattle can be calculated. For calculating the daily gross P-requirement, a general P absorption coefficient of 75% is assumed. The real absorption coefficient, however, depends on the P content of the ratio. In case of a low dietary P content, this coefficient will increase (Van Straalen et al., 2009) up to a level of even 90% (Valk and Beynen, 2003). The NRC requirements for the gross P supply (2001) are based on absorption coefficients of 64% for P in roughages and 70% for P in concentrates.

Table 2 provides the gross P-requirements for gestating and lactating dairy cattle with varying performance levels, according to the Dutch (COMV, 2005) and American (NRC, 2001) approach.

Table 2 Estimated dm intake and related gross P-requirements for gestating and lactating dairy cattle with varying performance levels, according to the Dutch (COMV, 2005) and American (NRC, 2001) approach

	Feed-intake	**P-requirement**			
		(g/cow/d)		(g/kg dm)	
	(kg dm)	*COMV*	*NRC*	*COMV*	*NRC*
Dairy cattle (650 kg BW)					
Gestating, wk -8-3, 800 VEM/kg	11,5	21	26	1,9	2,3
Gestating, wk -3-0, 920 VEM/kg	11,0	22	26	2,0	2,3
Lactating, 20 kg/d, 920 VEM/kg	18,5	47	56	2,5	3,0
Lactating, 40 kg/d, 970 VEM/kg	23,5	79	87	3,3	3,7
Lactating, 50 kg/d, 990 VEM/kg	27,5	96	106	3,5	3,9

dm = dry matter

From Table 2, it can be concluded that the stage of gestating has a very limited effect on the P-requirement of dairy cattle. The milk yield of lactating cows, however, largely affects their P-requirement. In the range of 20 to 50 kg milk/d, the daily P-requirement doubles. Although feed intake of the cattle also increases with higher milk yield, the P-content per kg of diet has to increase as well to meet the P-requirement at high milk yield levels.

3.2 P-requirements of pigs

The P-requirements of pigs are based on a factorial approach in which the requirement for maintenance and performance are distinguished. The P-requirements of pigs depends on their maintenance requirement and on their performance level in terms of body weight gain.
P-requirement of piglets and growing finishing pigs

Maintenance
The faecal endogenous P excretion as well as the unavoidable P losses are related to the dietary P supply (Jongbloed and Everts, 1992), and to the dm intake (Almeida en Stein, 2010). In the Netherlands, a system of apparent P-digestibility is used, in which the faecal endogenous P losses are included in the P-digestibility coefficients of the dietary ingredients. At a low available P level in the diet and at a common dietary Ca/available P ratio, the urinary P excretion is low. Faecal endogenous P excretion is set at 6 mg P/kg BW/d and unavoidable urinary P losses at 1 mg P/kg BW/d, resulting in a total endogenous P losses of 7 mg/kg BW/d (Jongbloed et al, 2003). In Germany and France, the standard for total endogenous P losses is assumed to be 10 mg P/kg BW/d (GfE, 2008; Jondreville and Dourmad, 2005). In the USA, faecal endogenous P losses are estimated to be 190 mg/kg feed, whereas urinary losses are set at 7 mg/kg BW (NRC, 2012).
Endogenous P-losses are relatively small in piglets and growing-finishing pigs, but relatively large in breeding sows, especially in gestating sows.

Performance
In piglets and growing-finishing pigs, P is mainly deposited in bones (75 - 80 %). The rest is deposited in protein (muscles and organs). In breeding sows, P is required for the growth of maternal tissues, the growth of foetuses, and for milk production.

Equations to estimate the P-requirement of piglets and growing-finishing pigs
In Table 3, an overview is provided of the equations that are used in Germany, France and the Netherlands for estimating the P-requirements.

Table 3 Equations and examples of the estimation of the P-requirement of piglets and growing finishing pigs (BW = body weight; EBW = empty body weight, kg).

Country	Equation Maintenance (mg/d)	Performance (g P/kg body weight gain)	Example for a pig with 80 kg BW Maintenance (g/d)	Performance (g P/kg body weight gain)
Germany	10 x BW	Up to 80 kg BW: 5.0 g/kg From 80 kg BW: 4.5 g/kg	0.8	Up to 80 kg BW: 5.0 g/kg From 80 kg BW: 4.5 g/kg
France	10 x BW	5.4199 – 2 x 0.002857 x BW	0.8	5.41
Netherlands	7 x BW	Ln P = 1.678 + 1.0037 ln EBW	0.7	5.32

In the German methodology, a P-efficacy for maintenance and body weight gain of 95% is assumed, while other countries are using a 100% P-efficacy of available P. In the Netherlands, the following equation is used for the conversion from empty body weight (EBW) to body weight (BW):

$$EBW (kg) = 0.012 + 0.923 \times BW + 0.00026 \times BW^2.$$

As shown in Table 3, the P-requirement of growing-finishing pigs depends on their BW. A rather small part of this requirement is necessary for maintenance, whereas the majority of the P- requirement is needed for body weight gain. The requirement for body weight gain slightly decreases with increasing age of the pigs.

P-requirement of a gestating sow
In the last decade, the performance levels of breeding sows have changed. The number of piglets per litter increased dramatically. Moreover, the body weight of a gilt at first mating increased from 120 to 130 kg.
There is no proof in literature that the P-maintenance level of breeding sows differs from piglets and growing-finishing pigs, and therefore the equations used for growing-finishing pigs can be applied on breeding sows as well (Van Krimpen et al., 2012).

P-requirement for growth of maternal tissue, and foetal growth
The growth of maternal tissue is largely affected by the diet composition and the feeding strategy during the gestation period. During the first 2 months of the gestation period, first parity sows have a high growth level of maternal tissues, which results in a relatively high P-requirement in that period. Second and higher parity sows have a relatively low P-requirement during the first 2 months of the gestation period. The P-requirement for development of maternal growth and uterine content (foetuses, placenta, intra-uterine liquid) is described by Everts et al. (1994). These authors assume a constant maternal protein retention during the whole gestation period (excluding for udder development). They developed the following equation for estimating the P-retention in foetuses during the gestation period:

$$\ln P_f = 4.591 - 6.389 * \exp^{(-0.02398 * (t-45))} + 0.0897 * n, \qquad (F1)$$

where P_f = P retention (g) in foetuses, , t = days in pregnancy, n = number of foetuses.

For gestating and lactating sows, 2.1 and 3.1 g available P/EW, respectively, is recommended in the Netherlands (CVB, 2010; 1 EW = 8.79 MJ NE). Available P is the amount of dietary P that is absorbed by the gut until the end of the ileum. These values are based on a second parity sow with 12.8 born piglets. These values assume a constant P-supply during the gestation period. From Table 4, however, it can be concluded that the available P requirement strongly increases from d84 of gestation onwards.

Table 4 Requirements of available phosphorus (aP, in g/d) of a second litter gestating sow with 13 foetuses

	Days in pregnancy						
	0	28	56	84	98	105	115
BW sow (kg)	150	166	184	206	214	219	228
aP-requirement for:							
Maintenance (7 mg/kg)	1.09	1.16	1.28	1.44	1.50	1.53	1.59
aP-requirement for performance:							
Maternal growth	0.53	0.53	0.53	0.53	0.53	0.53	0.53
Retention in bones	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Retention in placenta + udder	-	-	0.06	0.07	0.12	0.17	0.35
Retention in 13 foetuses	-	-	0.24	1.64	2.55	2.91	3.30
Total aP-requirement	2.41	2.50	2.92	4.49	5.50	5.95	6.58

As shown in Table 4, the P-requirement of gestating sows during the first halve of gestation is relatively low. In this period, the sows need P for maintenance and for maternal growth. From d56 of gestation onwards, the P-requirement further increases because of the increasing P retention in the foetuses.

P-requirement of lactating sows
The required available P amount of suckling piglets is based on their maintenance requirements and body weight gain. The P retention in suckling piglets is 5.4 g/kg gain of EBW. In these piglets, EBW = 97% of total BW (Jongbloed et al., 2002a). The P-digestibility of sow milk is 91%. The available P-requirement of a suckling piglet with a daily gain level of 250 g/d amounts 1.48 g/d.

During lactation, a small amount of P is released during protein degradation of maternal tissue. It is assumed that a second parity sow during the whole 28-d lactation period mobilizes 2.5 kg protein, thereby providing 9.6 mg P/kg protein (CVB, 2003).

Table 5 provides an overview of the requirement of available P (aP) of a second parity lactating sow. The effect of the level of daily gain of the piglets (225 and 250 g/d) on the P requirement of the sow is demonstrated as well.

Table 5 Estimated requirement of available phosphorus (aP, in g aP/d) of a second parity lactating sow (194 kg BW; 11.25 piglets with an average DG of 250 and 225 g/piglet/d)

	Requirement of aP (g aP/d)			
Piglet growth (g/d)	250		225	
Maintenance sow	194 x 0.007 =	1.36	194 x 0.007 =	1.36
Phosphorus mobilization	2.50 x 9.6/28 =	-0.86	2.50 x 9.6/28 =	-0.86
Piglet requirement	11.25 x 1.48 =	16.66	11.25 x 1.33 =	15.00
Total aP requirement		**17.16**		**15.50**

From Table 5 it can be concluded that about 97% of the P-requirement of the lactating sow is determined by the P-requirement of the piglets. To fulfil their high P-requirements, lactating sows are able to mobilize P from their bones.

3.3 P-requirements of poultry

Growing poultry

According to Van der Klis and Blok (1997) the requirement for available phosphorus (aP) for growing poultry can be calculated by use of the equation:

aP = ($P_{maintenance}$ + P_{growth}) / feed intake.

$P_{maintenance}$ = 0.014 * average weight * period length, in which:

- $P_{maintenance}$ is expressed in mg P per period
- Average weight is expressed in g. It is calculated as: (weight t2 – weight t1) * 0.60 + weight t1
- Period length is expressed in days (t2 – t1).

P_{growth} = weight t2 * $P_{carcass}$ t2 – weight t1 * $P_{carcass}$ t1, in which:

- P_{growth} is expressed as mg P deposited in the period
- Weight is expressed in g
- $P_{carcass}$ is expressed in mg P / g carcass
- t1 and t2 are the first and last day of the period, respectively.

Van der Klis and Blok suggested to increase a safety margin of 7.5% above the calculated aP requirement and an additional 25% for broilers in the period of 0 – 10 days of age. In Table 6, the aP requirement of broilers is provided for the period 0-10, 10-30 and 30-40 days of age.

Table 6 The requirement of available phosphorus (aP) of broilers for the period 0-10, 10-30 and 30-40 days of age.

t1	**t2**	**W1**	**W2**	**P_carcass** t = 1	**P_carcass** t=2	**P-maintenance**	**P-growth**	**Feed** intake	**aP** in feed	**aP in feed**_safety
d	**d**	**g**	**g**	**g/kg**	**g/kg**	**mg**	**mg**	**g**	**g/kg**	**g/kg**
0	10	42	281	2.3	3.3	26.0	831	288	2.97	4.00
10	30	281	1581	3.3	4.0	297.1	5397	2090	2.72	2.93
30	40	1581	2472	4.0	4.2	296.2	4058	1849	2.36	2.53

From Table 6, it can be concluded that fast growing broilers need a high (4.0 g/kg) aP-content during the starter phase (d0 -10), which can be reduced to 2.9 and 2.5 g/kg during the grower and finisher phase, respectively.

Laying birds:
According to Van der Klis and Blok, the requirements of available P (aP) of laying birds can be calculated by the equation:

$aP = ((P_{maintenance}$ part a $+ P_{production}) * 0.875 + P_{maintenance}$ part b) / feed intake, in which:

- aP is expressed as g aP/kg feed.
- $P_{maintenance}$ = 0.014 * average weight * period length.
- Average weight is expressed in g. It is calculated as: (weight t2 – weight t1) * 0.60 + weight t1.
- Period length is expressed in days (t2 – t1).

$P_{production} = P_{egg\ production} + P_{growth}$, in which

- $P_{production}$ is expressed in mg P per period.
- $P_{egg\ production} = P_{retention\ per\ egg}$ * period length, whereas $P_{retention\ per\ egg}$ = 2 mg P/g egg.
- $P_{growth} = 4.9 * growth_{period\ (t2-t1)}$.
- $Growth_{period\ (t2-t1)}$ = body weight gain (g) in the period (t2-t1).
- $P_{maintenance}$ part b = 2.7 * egg mass (g) in the period (t2-t1).

Van der Klis and Blok (1997) recommended for 20-36 wk old and 36-60 wk old laying hens a dietary aP-content of 3.2 and 3.0 g/kg, respectively.

3.4 Phosphorus digestibility and Phosphorus excretion

In chapters 3.1 to 3.3, the factors affecting P-requirements of dairy cattle, pigs and poultry are explained. The P-requirements for pigs and poultry are expressed on an available basis. This is, because these species can only partly digest the P that is provided by feed. This means that the indigestible part will be excreted by the animal. This chapter will focus on the factors that are influencing the P digestibility and consequently P excretion. Moreover, methods to adjust dietary P supply to the P requirement of the animals are discussed.

Approximately 60–80% of P in vegetal feed ingredients is in the form of phytate (Ravindran, et al., 1995). Due to the lack of phytate-degrading enzymes in their gastrointestinal tract (GIT), phytate P is almost completely unavailable to poultry and pigs. Because of the availability of phytase in the rumen, ruminants are able to digest two-thirds of the dietary phytate P. In the Netherlands, it is assumed that all P-sources have a similar P-absorbability of 75% (COMV, 2005).

Inorganic P is usually added to pig and poultry diets in order to meet nutritional requirements for optimizing growth performance and bone strength of the animals. On the one hand, the excess amount of P which is present in phytate form is excreted in manure, so it would be a cause of environmental pollution. Phosphorus pollution has been a big concern and lots of research has been done to mitigate this problem especially, by using microbial phytase.

In pig diets, P-reduction is possible by 1) precisely adjusting digestible P supply to P requirements (phase feeding), 2) adding more phytase to the diet, 3) improving P digestibility of the diet, by selecting ingredients with low margin between total P and available P, and 4) increasing nutrient density of the diet.

Rationale, mechanism of action
Nutritional research in relation to environmental pollution has focused mainly on reducing the dietary P input, and on their more efficient utilization. To achieve this, it is important to supply dietary P in close accordance with the animals' requirement. This requires adequate knowledge about the digestibility of P in the feed used, and on the requirement for this nutrient. It has been recognized that the nutritional requirements in different countries may vary because of differences in housing conditions, genotype of the animals, level of feeding, major ingredients used in the diets and response criteria. Furthermore, it is possible to enhance the digestibility of P in feeds by using extrinsic enzymes. In addition, the excretion of P can be further reduced by exchanging less digestible feedstuffs by better digestible ones. By the introduction of (multi)phase feeding, also a reduction in P excretion can be obtained. Moreover, by improved performance (improved types of pigs) reduction of the excretion of P can be achieved. In this respect also optimal management with regard to housing and health status of the pigs and feeding strategy, which may improve feed conversion ratio, will be beneficial for the environment.

3.4.1 Digestible P in feedstuffs

The nutritive value of total P of a diet is evaluated by its apparent faecal digestibility. Table 1 shows that there are large differences in P digestibility among feedstuffs of plant origin. There are also substantial differences among those from animals and feed phosphates. The large variation among and within a feedstuff is attributed to differences in phytate P content, phytase activity, and processing (Jongbloed and Kemme, 1990). The requirements for phosphorus are also expressed in terms of digestible P (Jongbloed et al., 2003).

Table 6 Apparent digestibility of P (%) in some feedstuffs for pigs (CVB, 2007)

Feedstuff	**P**
Barley	39
Maize	20
Wheat	48[a]
Wheat middlings	30[b]
Soybean meal extr.	39
Rapeseed meal extr.	27
Sunflower seed extr.	15
Peas	45
Fishmeal (CP 580-630)	77

[a] wheat contains 1000 phytase units per kg
[b] wheat middlings contain 3000 phytase units per kg

3.4.2 Adjusting digestible P supply to P requirements

Based on the P contents of different categories of pigs, available P requirements per unit of energy (EW; 1 EW equals 8.79 MJ NE or 12.55 MJ ME) are estimated by use of the factorial method. The estimated digestible P and total Ca requirements per pig category are shown in Table 2.

Table 7 Practical recommendations of available P (aP) en Ca in pig diets (Jongbloed et al., 2003)

Category	**aP (g.kg EW^{-1})**	**Ca (g.kg EW^{-1})**
Weanling pig until 2 wk after weaning	3.2	8.0
Weanling pig from 2 wk after weaning	3.4	9.5
Grower pig (25 to 45 kg)	2.4	6.9
Grower pig (45 to 70 kg)	2.1	6.3
Finisher pig (70 kg to slaughter)	1.9	5.7
Finisher pig (45 kg to slaughter)	2.0	6.0
Pregnant sow (until 70 d. of pregnancy)	1.5	5.0
Pregnant sow (from 70 d. of pregnancy)	2.2	7.3
Pregnant sow (whole pregnancy)	2.1	6.9
Lactating sow	2.7	7.7

The recommended available P content of the diet highly depends on the physiological status of the pig category. As the recommended concentration of digestible P per kg feed decreases as LW of grower-finisher pigs increases, phase-feeding systems can be introduced to further reduce P excretion.

3.4.3 Adding more phytase to the diet

Plant ingredients used to formulate pig diets may contain from 0.7 to 3.5% of phytate (Cosgrove, 1980). They are of very limited digestibility for pigs. Therefore, feed manufacturers and farmers have to add inorganic P from feed phosphates to their pig diets. To enable de-phosphorylation of the dietary phytates, intrinsic or extrinsic (microbial) phytases can be used. Since 1990, several experiments with exogenous microbial phytases were reported to quantify their effect on the apparent digestibility of P. A survey of a large part of these studies has been presented by Jongbloed et al. (1996; 2000). Most studies show an exponential dose-response curve (Figure 2). From this figure, it can be concluded that addition of the first 500 phytase units (by use of the microbial phytase Natuphos) generates about 0.8 g available P per kg of diet, whereas addition of 1000 phytase units generates 1.0 g available P per kg of diet.

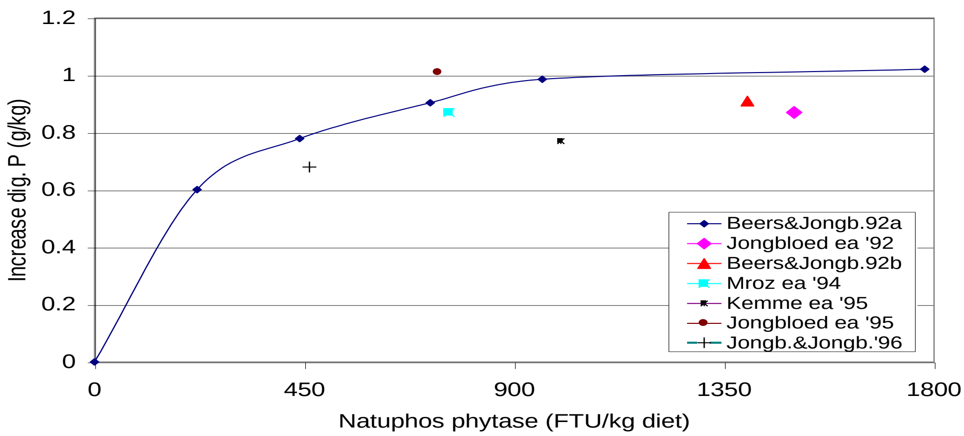

Figure 2 Dose-response effect of 3-phytase on the amount of available P generated in diets with more than 50% maize and soybean meal (Jongbloed et al., 1996; 2000)

3.4.4 Applicability

Reducing phosphate excretion by phase feeding is especially applicable in gestating sows and grower - finisher pigs (Van Krimpen et al., 2012). Adding more phytase to the diet and improving P digestibility of the raw materials is applicable in diets of all categories of pigs. The environmental perspectives of increasing the nutrient density of the diet are largest in grower - finisher pigs. Supplementing high energy diets to lactating sows, however, probably could also be a perspective option.

Effectiveness, including certainty
The impact of different feeding strategies on phosphorus excretion in grower – finisher pigs are summarized in Table 8, as presented by Van Krimpen et al. (2010). Starting point is based on the average performance and P content in the Dutch grower - finisher husbandry of 2007.

Table 8 The impact of different feeding strategies on phosphorus excretion in grower - finisher pigs, based on the average Dutch performance in pig husbandry of 2007 or 2009 (Van Krimpen et al., 2010)

Grower – finisher pigs from 25 kg to 110 kg		**Control**	**Phase feeding**	**More phytase**	**Control energy diet**	**High energy diet**
Starting points	Unit	**2007**	**2007**	**2007**	**2009**	**2009**
Days to slaughtering	d	117	117	117	114	111
Starter weight	kg	25.6	25.6	25.6	23.3	23.3
Slaughter weight	kg	116.6	116.6	116.6	115.4	117.1
Feed conversion		2.75	2.75	2.75	2.62	2.00
Daily gain	g/d	779	779	779	808	844
P content starter diet	g/kg	**4.8**	**4.8**	**4.6**	**4.6**	**4.4**
P content grower diet	g/kg	**4.7**	**4.7**	**4.5**	**-**	**-**
P content finisher diet	g/kg	**4.7**	**4.5**	**4.3**	**4.8**	**3.8**
Total feed intake	kg	250.3	250.3	250.3	241.3	187.6
Per year						
Conversion factor to year		3.12	3.12	3.12	3.20	3.28
Total P intake	kg	3.69	3.62	3.46	3.68	2.43
P retention in meat	kg	1.53	1.53	1.53	1.58	1.65
P excretion	kg	2.17	2.09	1.94	2.09	0.77
Relative P excretion	**%**	**100**	**96**	**89**	**100**	**37**
P retention	**%**	**41.3**	**42.2**	**44.1**	**43.1**	**68.1**

Phase feeding could reduce P excretion of grower - finisher pigs by 4%, whereas the mixture of phase feeding and additional phytase in the diet could reduce P excretion by 11%. Applying high energy diets might even reduce P excretion by 63% .

The impact of different feeding strategies on phosphorus excretion in breeding sows and piglets are summarized in Table 9. Starting point is based on the average performance and P content in the Dutch breeding pig husbandry of 2008 (Van Krimpen et al., 2010).

Table 9 The impact of different feeding strategies on phosphorus excretion in breeding sows and piglets, based on the average Dutch performance in breeding pig husbandry of 2008

Breeding sow and piglet to 25 kg		**Control**	**Phase feeding**	**More phytase**	**Increased P digest.**
Starting points	**Unit**	**2008**	**2008**	**2008**	**2008**
Live born piglets/sow/year		30.9	30.9	30.9	30.9
Weaned piglets/sow/year		26.9	26.9	26.9	26.9
P content piglet diets	g/kg	**5.4**	**5.4**	**5.2**	**5.1**
P content lactation diet	g/kg	**5.5**	**5.5**	**5.2**	**5.0**
P content gestation diet < 80 d gestation	g/kg	**5.0**	**4.4**	**4.4**	**3.0**
P content gestation diet > 80 d gestation	g/kg	**5.0**	**5.0**	**4.7**	**4.4**
Per sow per year					
P-intake					
Piglet diets	kg	4.26	4.26	4.11	4.01
Lactation diets	kg	2.28	2.28	2.16	2.07
Gestation diet < 80 d gestation	kg	2.44	2.15	2.15	1.46
Gestation diet > 80 d gestation	kg	1.31	1.31	1.23	1.16
Total P-intake	**kg**	**10.30**	**10.00**	**9.64**	**8.71**
P retention in growth sow, piglets, mortality piglets	kg	3.94	3.94	3.94	3.94
P excretion	kg	6.35	6.06	5.70	4.76
Relative P excretion	**%**	**100**	**95**	**90**	**75**
P retention	**%**	**38.3**	**39.4**	**40.9**	**45.3**

Phase feeding could reduce P excretion of breeding sows by 5%, whereas the mixture of phase feeding and additional phytase in the diet could reduce P excretion by 10%. The use of raw materials with a low content of indigestible P might reduce P excretion even by 25%.

Time frame
The different feeding strategies that might reduce P excretion can be implemented in pig husbandry in the short-term (Van Krimpen et al., 2010). Data from practical farms show that some pig farmers already are realizing significant reductions in P excretion without negatively affecting technical or economic performance.

Environmental side-effects / pollution swapping
There is a growing concern about the exhaustibility of our natural P resources (Van Krimpen et al., 2010). Reducing the P content of pig diets will contribute to a well-balanced use of P resources.

Relevance, potential for targeting, administrative handling, control
Before delivering the feed to the farmer, the feed producer regularly has to determine the P content of the pig diets. Data of analysis should be registered in a control system, which will be inspected at random. Phosphate content of manure should be determined before transport (Van Krimpen et al., 2010).

Costs: investment, labor
Additional costs or savings of P-low diets depend on the market prices of raw materials and inorganic phosphorus sources and are fluctuating over time. To realize (multi-)phase feeding, farmers need to invest in additional equipment, like feed silo's. Feeding systems, however, differ in the level of sophistication, so no general statement about additional costs can be made. The phosphorus level in pig feed could fall by 10-20% at moderate additional costs. The manure then generally contains up to 20% less phosphate. Further reduction lead to greatly increased additional costs (Kortstee et al., 2011).

3.5 Executive summary

The following conclusions can be drawn from this literature review as described in chapters 3.1 to 3.4

- Phosphorus, that is not available for the animal, cannot be used for metabolic processes and will be excreted by the faeces.
- The available phosphorus requirement of livestock animals depends on their maintenance requirements and their production levels in terms of body weight gain, milk production, egg production or progeny production.
- The amount of consumed phosphorus that is not deposited in meat, milk, egg, or progeny will be excreted by the faeces and urine.
- Phosphorus excretion can be reduced by:
    - precisely adjusting the available P supply on the P requirements of the animals, e.g. by phase feeding
    - reducing the dietary unavailable phosphorus content, e.g. by adding (more) phytase to the diet
    - selecting dietary ingredients with a high available P content
    - improving the P availability of ingredients, e.g. by acidification or soaking in water
    - increasing nutrient density of the diet.

4 Default P excretion factors of livestock

As mentioned already in chapter 3.1 of Task 2 (Sebek et al., 2014), national total P excretion should be calculated in principle as the registered animal numbers x average excretion per animal (kg/year). However, animal numbers refer to different categories of animals and thus to different P excretion per average animal in each category. In fact the national total P excretion have to be calculated as the sum of the excretions of each animal category. Large differences in categorization of farm animals between countries makes comparing average P excretions per animal per year as such less meaningful. On the other hand, the perhaps most important factor affecting the accuracy and quality of the calculated national P excretion is not the categorization of farm animals but 'data origin'. Data origin depends on accessibility of information about animal numbers within a specific category and estimates of P contents in feed and P retention in animal products. The availability of this information is usually related to 'big changes in the animals life' as (for pigs) birth, culling, transfers to different housing. At these moments animals are counted and often weighted and between these moments feed intake and feed composition could be registered. However, slaughter weight and age at each event described may differ per country or region due to differences in the dominant housing and/or feeding systems. In order to ensure the best data origin, animal categorization should be a reflection of the local animal husbandry system and measurements should refer to these categories. When existing systems for uniform categorization (e.g. Farm System Survey or Livestock registers) differ from local animal categories the local data have to be recalculated to fit to the new animal categories. The extent of the differences between local and uniform animal categories will determine the impact of these differences on the quality of calculated excretion coefficients.
P-excretion factors per animal category, however, are not available for all EU countries. Therefore, in this chapter default P-excretion factors are developed for estimating the national P-excretion in these countries.
In Task 2, (Sebek et al., 2013) the phosphorus excretion factors of livestock of the 10 selected EU countries, if available, are described. This task aims to develop default P-excretion factors as function of animal type, and in line with the methodology proposed in Task 5, to be used by countries that do not have all data required for the proposed methodology in Task 5. We calculated the default P-excretion factors per animal category by averaging the P-excretion factors per animal category as used in the different countries. For dairy cattle, two default categories were developed, taken the performance level of the cattle into account.

Table 10 provides the P-excretion factors in different countries for cattle (kg/animal/year).

Table 10 P-excretion factors in different countries for cattle (kg/animal/year)

Category	Description	Denmark	France	Germany	Ireland	Netherlands
Lactating cow of large breed	Dairy cow of FH or similar breed and producing 8,000 – 10,000 kg of milk per year	20.1	15.6-18.0	18.4-20.0		18.3-21.6
Lactating cow of Jersey breed	Dairy cow of Jersey breed or similar breed and producing on average 6,000 – 8,000 kg of milk per year	17.7	15.6-18.0	16.1	13.0	14.6-18.0
Suckler cow	Lactating cow including 0.9 calf/year			12.1-15.5	10.0	11.9
Young stock <1 year	Young female animal reared to replace less-productive dairy cows, age between 0 and 12 months	3.0			3.0	4.2
Young stock > 1year	Young female animal reared to replace less-productive dairy cows, age between 12 and 24 months	6.6		6.7- 8.1	8.0	9.7
Fattening cattle large breed	Non-lactating cattle fattened from 6 months until slaughter at 440 kg	3.8				5.2

Based on the values in Table 10, the default P excretion factors of the different cattle categories are presented in Table 11.

Table 11 Default P excretion factors (kg/animal/year) of different cattle categories

Category	Description	Default value
Lactating cow of large breed	Dairy cow of FH or similar breed and producing 8,000 – 10,000 kg of milk per year	19.7
Lactating cow of Jersey breed	Dairy cow of Jersey breed or similar breed and producing on average 6,000 – 8,000 kg of milk per year	16.1
Suckler cow	Lactating cow including 0.9 calf/year	12.4
Young stock <1 year	Young female animal reared to replace less-productive dairy cows, age between 0 and 12 months	3.4
Young stock > 1year	Young female animal reared to replace less-productive dairy cows, age between 12 and 24 months	7.8
Fattening cattle large breed	Non-lactating cattle fattened from 6 months until slaughter at 440 kg	4.5

Table 12 provides the P-excretion factors in different countries for pigs (kg/animal/year).

Table 12 P excretion factors for pigs (ex animal) in different counties (kg/animal/year). Phosphate excretion coefficients between brackets

Category	Denmark	Estonia	France[3]	Germany[4]	Ireland	Italy	Netherlands	Poland	Spain[2]	UK
Average present sow incl. piglets to weaning	5.7[1] (13.1)		4.8 – 6.11 (11.0–14.0)		5.83 (13.35)		5.02 (11.50)			5.83 (13.35)
Average present sow incl. piglets up to the grower period				6.8-8.1 (15.6-18.6)			6.43 (14.72)			
Weaned piglets	0.14[2] (0.32)		0.11 – 0.14 (0.25–0.32)	0.63-0.71 (1.44-1.63)	0.94 (2.15)		0.57 (1.31)			0.94 (2.15)
Growing–finishing pig	0.54[2] (1.23)		0.63 – 0.92 (1.44–2.11)	2.1-2.6[5] (4.8-6.0)	1.71 (3.92)		1.88 (4.31)			1.71 (3.92)

[1]) Based on a performance level of 26.0 weaned piglets (7.3 kg) per sow per year.
[2]) On an animal basis.
[3]) First value is based on a 2-phase feeding system; the second value is based on a standard feeding system.
[4]) Based on a performance level of 22.0 weaned piglets (28 kg) per sow per year. The first value is based on N/P low diets, the second value is based on standard diets.
[5]) Based on growth rate of 800 g/d.
[6]) Range of 25 – 100 kg BW.

The variation in P-excretion coefficients between countries is relatively low. The relatively high level of P-excretion in German sows seems to be related to the high feed consumption of these animals. The P-content of the Irish and UK pig diets is relatively high, as well as the P-content of the Danish pigs, resulting in slightly higher P-excretion coefficients of pigs in those countries.

Based on the values in Table 12, the default P excretion factors of the different pig categories are presented in Table 13.

Table 13 Default P excretion factors (kg/animal/year) of different pig categories

Category	**Default value**
Average present sow incl. piglets to weaning	5.5
Average present sow incl. piglets up to the grower period	7.1
Weaned piglets	0.76
Growing–finishing pig	2.0

Table 14 provides the P-excretion factors in different countries for poultry (kg/animal/year).

Table 14 P excretion coefficients for poultry (ex animal) in different counties (kg/animal/year). Phosphate excretion between brackets.

Category	Denmark	Estonia	France	Germany	Ireland[3]	Italy	Netherlands	Poland	Spain	UK
Broiler chickens, 30 days[1]	0.036 (0.082)									
Broiler chickens, 32 days[1]	0.039 (0.090)			0.07-0.09 (0.16-0.21)						
Broiler chickens, 35 days[1]	0.045 (0.103)									
Broiler chickens, 40 days[1]	0.057 (0.130)			0.08-0.11 (0.18-0.25)	0.10-0.13 (0.22-0.29)		0.075 (0.172)			0.10-0.13 (0.22-0.29)
Broiler chickens, 45 days[1]	0.072 (0.164)		0.011 (0.025)[2]							
Barn-reared chickens, 56 days[1]	0.122 (0.278)		0.017 (0.038)[2]							
Broiler chickens organic, 81 days[1]	0.135 (0.310)		0.030 (0.069)[2]							
Laying hens, free-range	0.181 (0.414)		0.136 (0.311)		0.17-0.22 (0.39-0.49)					0.17-0.22 (0.39-0.49)
Laying hens, organic	0.228 (0.522)		0.133 (0.304)							
Laying hens, barn-reared	0.178 (0.408)									
Laying hens, cages	0.155 (0.355)		0.134 (0.307)	0.148 (0.339)	0.16-0.20 (0.36-0.46)		0.172 (0.394)			0.16-0.20 (0.36-0.46)

[1]) The first value is based on N/P low diets, the second value is based on standard diets.
[2]) On an animal basis.
[3]) The first value is based on diets with addition of microbial phytase; the second value is based on diets without microbial phytase addition.

P-excretion levels of broilers and laying hens show some variation, depending on whether or not the use of microbial phytase, the strain and the length of the growing period.

Based on the values in Table 14, the default P excretion factors of the different poultry categories are presented in Table 15.

Table15 Default P excretion factors (kg/animal/year) of broilers and laying hens

Category	**Default value**
Broiler chickens, 40 days	0.098
Laying hens, free-range	0.183
Laying hens, cages	0.166

5 Conclusions

The following conclusions can be drawn from this study.

- Phosphorus, that is not available for the animal, cannot be used for metabolic processes and will be excreted by the faeces.
- The available phosphorus requirement of livestock animals depends on their maintenance requirements and their production levels in terms of body weight gain, milk production, egg production or progeny production.
- The amount of consumed phosphorus that is not deposited in meat, milk, egg, or progeny will be excreted by the faeces and urine.
- Phosphorus excretion can be reduced by:
    - precisely adjusting the available P supply on the P requirements of the animals, e.g. by phase feeding
    - reducing the dietary unavailable phosphorus content, e.g. by adding (more) phytase to the diet
    - selecting dietary ingredients with a high available P content
    - improving the P availability of ingredients, e.g. by acidification or soaking in water
    - increasing nutrient density of the diet.

Moreover, default P excretion factors for different categories of livestock are provided. These factors are based on the available values from the selected countries. Most values originated from West European countries, because values were lacking in the other countries.

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