Towards an optimal utilisation of phosphorus sources in growing meat ducks

M. Rodehutscord, Institut für Ernährungswissenschaften, Universität Halle-Wittenberg, D-06099 Halle (Saale), Germany. E-mail: markus.rodehutscord@landw.uni-halle.de

Abstract

Optimal utilisation of limited phosphate resources in animal feeding requires detailed knowledge of both the requirement for available P, and the availability of P from relevant feed ingredients. In growing ducks, the P concentration of gained body weight and the inevitable P losses determine the requirement for available P. The concentration of available P needed in the diet then depends on the feed conversion ratio. Plant and mineral feedstuffs contribute to the available P content of the diet depending on their respective availability. This review summarises the literature on P nutrition in ducks with regard to factors of the P requirement and considerations on P availability, including the use of microbial phytase. The P content in body weight gain is 5.0-5.5 g/kg in young ducks, and it probably decreases with age. Inevitable P losses were not yet quantified and can only be estimated to account for 1 g/kg of feed intake. Availability of P from plant-based diets without P supplements and phytase ranged between 28 and 49%. Availability of P from different mineral sources ranged between 77 and 100%. Microbial phytases were efficient in improving the availability of P from plant-based diets. A simple model is presented, which allows flexible calculations of the necessary P concentrations in the diets for ducks.

Abbreviations used: **aP**: available phosphorus; **BW**: body weight; **BWG**: body weight gain; **d**: day; **MCP**: monocalcium phosphate; **nPP**: nonphytate phosphorus; **tP** total P; **wk**: week

1 Introduction

Duck meat production is continuously increasing on the global and European scale. Average annual growth in duck meat production between 1998 and 2003 was 3% in Europe and 6% worldwide (FAO, 2005). About 435,000 tonnes of duck meat were produced in Europe in 2003, approximately 13% of the global production. 58% of this volume was produced in France. Of all European countries, France and Hungary have the highest duck meat production per hectare of arable land.

Professional duck farming is, for economic reasons, often associated with high intensity and large-sized farms. With regard to phosphorus (P) and its supply from different sources the consequences are similar to those known for other livestock: (1.) The animal's requirement should be met and deficiencies should not occur, but (2.) excessive intake should be avoided in order to reduce feeding costs, minimise P excretion, and contribute to sustainable use of limited global phosphate resources. This is of particular interest in Europe since meat and bone meals were banned from livestock feeding (Rodehutscord *et al.*, 2002).

In feed compounding, finding the right balance between meeting the duck's requirement and minimising the environmental load is not easy. Recommendations for the dietary content of nonphytate phosphorus (nPP) or available P (aP) exist (WPSA, 1985; NRC, 1994). Experimental data for these recommendations were, however, rare. Furthermore, the duck's growth and feed conversion potential was continuously improved over the years, which may have caused a change in the requirements of modern-type meat ducks in comparison with older types. In growth studies from our institute, male Pekin ducks between 6 to 7 wk approached a body weight (BW) of about 3.2 kg with an average feed/gain ratio of 2.42 (Timmler and Rodehutscord, 2001). In a recently concluded study with ducks from the same breed, the BW of males already after 5 weeks was 2.6 kg, and the feed/gain ratio was 1.88 (unpublished). King *et al.* (2000) reported 3.8 kg BW for 7 wk old Pekin ducks. In comparison with other poultry species, growth rate of young Pekin ducklings is higher than the growth of broilers and turkeys of the same age (Applegate *et al.*, 2005; Rodehutscord and Dieckmann, 2005). Differences in growth may also exist between Pekin ducks and Muscovy ducks or crossbreeds of these (mule ducks), but almost all published studies were conducted with Pekin ducks. A brief summary of studies on the duck's requirement for P and calcium (Ca) is part of the review written by Elkin (1987).

The objective of this paper is to provide a new summarisation of the published results and ideas about P nutrition and P evaluation in ducks. This is done along the concepts of the factorial approach. First, individual factors of the requirement for aP shall be considered. Second, availability of P from different dietary sources is addressed, including relevant factors for availability studies. In this paper the term "utilisation" generally describes the proportion of P intake that is retained by the animal. "Availability" is understood as a criterion of feed evaluation, which describes the potential of a P source to be utilised by the animal. Because the metabolism of P and Ca is closely linked, Ca is also addressed in chapters when data were available. Finally, concluding calculations for the adjustment in P supply during the growth phase will be suggested.

2 Factors of the net requirement of ducks

2.1 Phosphorus accretion and P concentration in body weight gain

The quantitatively most important part of the requirement of growing ducks is the accretion in the body, including all structural and physiological functions of phosphate. The sub-committee on mineral requirements of working group number 2 (Nutrition) of the European Federation of Branches of the WPSA assumed a continuous increase in the P content of body weight (BW) from 3.1 (hatch) to 5.7 g/kg (wk 7) in Pekin ducks, and from 3.1 (hatch) to 6.3 g/kg (wk 12) in Muscovy ducks (WPSA, 1985). The value for hatchlings (3.1 g/kg) was confirmed for Pekin ducks by Rodehutscord *et al.* (2003), indicating that this remained unchanged over the years. In studies with graded P levels, Pekin ducks achieved a plateau in the P concentration of body weight gain (BWG) of 5.6 g/kg at 2 wk of age, while the value was slightly lower (5.1 g/kg BWG) in 5 wk old ducks (Rodehutscord *et al.*, 2003). In 7 to 17 d old ducks, Rush *et al.* (2005) measured average values for feed/BWG ratio and P utilisation of 1.87 and 46%, respectively. In combination with the P content of their diet (6.4 g/kg), this allows for calculating a P concentration in gained BW of 5.5 g/kg (1.87 × 6.4 × 0.46). Using data from another experiment with ducks growing from hatch until d 14, the same calculation yields 5.1 g P/kg BWG (1.47 × 6.4 × 0.54, data from Exp. 2 by Rush *et al.*, 2005). Using the corresponding values for Ca under consideration of all diets that contained more than 8 g Ca/kg, estimates for the Ca content in BWG of 9.6 and 8.8 g Ca/kg can be made from Exp. 1 and 2 by Rush *et al*. (2005).

No data were found for the P content in BWG of ducks older than 5 wk. Bochno *et al.* (2005) described a continuous decrease in the relative contribution of bones to the carcase of ducks, from 21% in wk 2 to 13% in wk 13. Because the P content in bones is much higher than in all other body tissues, it can be assumed that the P content of the body also declined. However, more detailed calculations on P accretion cannot be made from these data.

It can be concluded that the factor "P concentration in BWG" is not a constant. It is around 5 g P/kg BWG during the 2 to 3 wk post hatch. It probably decreases with age, which is a consequence of changes in carcase tissue composition. These changes may be less relevant for commercial growth periods that last only 6 to 7 wk. Since data on P accretion and P concentration in BWG are to be obtained with relative ease by comparative body analysis or balance studies, further studies on this subject with different breeds and in different growth phases are suggested in order to make the requirement estimates more accurate.

2 Inevitable phosphorus losses

Even in the (theoretical) situation of zero P intake, animals excrete P. This inevitable loss is caused by endogenous secretion, and it is assumed that it depends on BW or feed intake. In turkeys up to 10 wk of age, it was found that the daily inevitable loss does not exceed 10 mg/kg BW (Dänner *et al.*, 2005). The Gesellschaft für Ernährungsphysiologie (GfE, 1999) assumed a value of 83 mg P/kg BW per day for chickens, but stated that the experimental basis for this assumption is weak. Similarly, there are no data published on inevitable P losses of ducks.

Estimates can be made using diets with very low P concentration. The inevitable loss can be estimated by regression analysis from dose-response studies when P excretion is extrapolated to zero P intake (Rodehutscord *et al.*, 1998; Dänner *et al.*, 2005). This principle can be applied to duck data as well, as shown in Fig. 1. However, the estimated intercept of the regressions from Fig. 1 can only be interpreted with great care, because the extrapolation to zero intake is very wide. This uncertainty is reflected in the high SE of the estimates for the intercepts. Only in the sense of a best guess can a value of 110 mg/kg BW per day or 1 g/kg of feed intake be concluded as an average from the three studies in Fig. 1. Further experiments on this subject with a very low range of P intake are suggested in order to improve the goodness of this estimate.

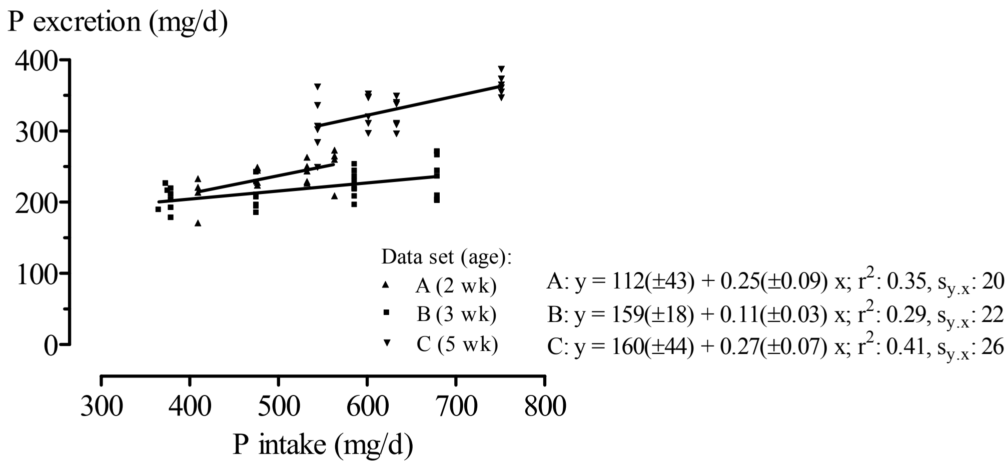

Fig. 1: Relationship between intake and excretion of P by Pekin ducks determined in different experiments (A,C: Rodehutscord *et al.*, 2003; B: Rodehutscord and Dieckmann, 2005). Only the range of marginal P supply was considered. P supplements were made with MCP. Average BW was 0.8 (A), 1.6 (B), and 1.8 kg (C), and feed intake was 100 (A), 140 (B), and 180 g/d (C) in these studies.

3 Phosphorus availability

3.1 Methodological aspects and data for P sources

Availability is commonly understood as a potential of a feed, describing the maximum proportion of P that can be utilised by the animal. Different techniques were applied to determine the P availability in poultry, such as quantitative measurements of excretion in balance studies or measurements of precaecal digestibility. Alternatively, P sources are often ranked to a reference source on the basis of the slope-ratio technique using single bones. Irrespective of what technique is applied, measurements must be made at a supply level below the requirement in order to force the animal towards highest possible utilisation. Without this restriction, measurements can hardly be compared, and they cannot be regarded as availability. Consequently, P availability studies need to be designed considering the P requirement of the species in the relevant growth phase. For instance, for studies on P

availability with 3 wk old ducks, Wendt and Rodehutscord (2004a) suggested that the level of total P in a corn soybean meal-based diet should not exceed 3.3 g P/kg.
Dose response studies with graded levels of monocalcium phosphate (MCP) showed a nonlinear response in P retention, giving the marginal efficiency of P utilisation a pronounced maximum before the requirement is met (Rodehutscord *et al.*, 2003; Wendt and Rodehutscord, 2004a). However, Wendt and Rodehutscord (2004a) concluded that within a certain range of supplementation, the response is almost linear (see also Fig. 1). Hence, different sources can be compared with less experimental effort, because only one supplementary level is to be used.
When inorganic P sources were supplemented at a level of 0.9 g P/kg to a low-P basal diet, these sources were utilised between 77 and 100% by Pekin ducks (Fig. 2). In contrast, when the supplementation was 1.9 g P/kg of diet, utilisation for the same sources was lower, indicating that only measurements made at the low supplementation level can be regarded as availability. This relevance of the supplementation level was also obvious in chicken studies (Lima *et al.*, 1997; Leske and Coon, 2002). The overall level of availability of mineral P sources for ducks is high (Fig. 2).

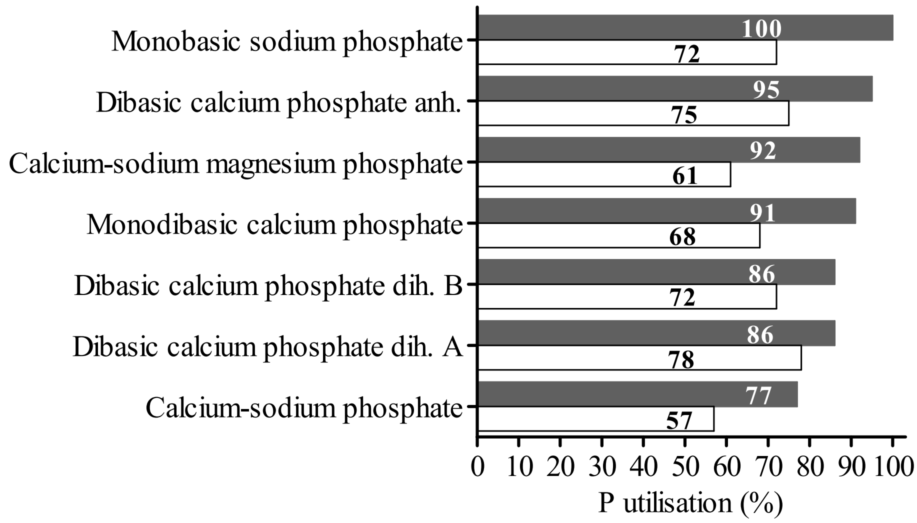

Fig. 2: Efficiency of utilisation of P from different inorganic sources, determined with Pekin ducks in balance trials. Phosphate sources were supplemented to a low-P basal diet at either 0.9 (grey bars) or 1.9 (white bars) g/kg of diet (Wendt and Rodehutscord, 2004a).

In contrast to mineral P sources, other relevant sources, namely cereal grains and legume seeds including related processing products, were not studied for P availability with a comparable method. A large proportion of P in these feeds is contained as phytate P (Eeckhout and De Paepe, 1994), and is often assumed to be completely unavailable to poultry. Because phytase can be found in some of these feedstuffs (for example wheat) (Eeckhout and De Paepe, 1994), and this phytase is active in the digestive tract, P availability may be different amongst plant feedstuffs. Measurements so far were not made with individual plant ingredients. This incompleteness of feed data still stands against the application of an aP system in duck feeding.

3.2 Effect of age and duck type

The effect of age on P availability was hardly studied in ducks. Marginal efficiency of utilisation of P from MCP was similar in 12 to 17 and 30 to 35 d old Pekin ducks

(Rodehutscord *et al*., 2003), indicating that an age effect either does not exist or is irrelevant. The small intestinal activity of alkaline phosphatase, expressed in relation to mucosa mass or area, was not significantly affected by the age of Pekin ducklings between 1 and 7 wk (King *et al.*, 2000). Because this enzyme is involved in phytate hydrolysis, this observation can carefully be regarded as support for the hypothesis that P utilisation is not affected by age in growing ducks.

Jamroz *et al.* (1998) compared 5 to 6 wk old Muscovy ('Barbarie') and mule ducks. They fed diets with a P content of 5.3 g/kg and found no consistent differences in P utilisation between the two duck types. Comparisons between Pekin ducks and other ducks were not found in the literature.

3.3 Effects of calcium supply

When diets containing 6.6 g P/kg were used, Pekin ducks had higher BWG from 7 to 15 d post hatch with 9.5 g Ca/kg of diet as compared to 7.4, 8.5, or 11.1 g/kg (Rush *et al.*, 2005). This indicates that Ca levels recommended by NRC (1994) (6.5 and 6.0 g/kg for ducks <2 wk and >2 wk, respectively) may be too low for modern-type growing ducks. As discussed earlier for P, this could be a consequence of an improved feed/BWG ratio. Based on some data from the 1970ies, the review by Elkin (1987) indicated that a dietary level of about 6 g Ca/kg of diet was sufficient for both Pekin and mule ducks.

Utilisation of P in a diet that contained 6.6 g P/kg was 46%, and it was not affected by concentrations of Ca in the diet between 7.4 and 11.1 g/kg (Rush *et al*., 2005). In contrast, praecaecal P digestibility increased from 44 to 57% when determined with the same birds. Most likely, intestinal P absorption was regulated depending on Ca supply, but absorbed P could not be retained and was excreted with urine. In contrast to this finding, at a marginal level of P supply, Wendt and Rodehutscord (2004a) found a significant effect of the Ca:P ratio in the diet on P utilisation. In diets containing 2.6 g P/kg and without an inorganic P supplementation, P utilisation decreased from 49% at Ca:P = 1.2:1 to 40% at Ca:P = 2.0:1. This effect of the Ca:P ratio decreased with an increase in the dietary P level. The authors concluded that in P availability studies (on the low level of P supply), a Ca:P ratio of about 2:1 should be used.

3.4 Effect of vitamin D_3

The NRC (1994) recommends duck diets contain 400 IU vitamin D_3/kg and states that the data basis is weak. Rush *et al*. (2005) compared 826 and 8,260 IU vitamin D_3/kg at different levels of Ca (6 to 12 g/kg of diet) and 6.4 g P/kg. They found no effect of vitamin D_3 on growth, feed conversion, tibia ash and bone ash in Pekin ducks during the 2 wk post hatch (Table 1).

Table 1: Effect of vitamin D_3 supplementation in Pekin ducks growing 14 days post hatch with a diet containing 6.4 g P/kg (Rush *et al.*, 2005)[1]

Formulated D_3 level IU/kg of diet	Tibia ash	Toe ash	P utilisation[2]	pc P digestibility[3]
	% of dry, defatted bone		% of P intake	
826	48.5	15.9	53.6	53.8
8,260	49.1	15.8	53.6	53.2

[1] Pooled data for the main effect vitamin D_3 level. No significant vitamin D_3 effect was found.
[2] P retention/P intake×100. [3] Precaecal digestibility, determined between Meckel's diverticulum and the ileo-caeco-colonic junction.

Also, precaecal P digestibility and P utilisation were not affected by the vitamin D_3 level. Similarly, broiler chickens did not significantly respond in P utilisation when vitamin D_3 was increased from 1,100 to 8,800 IU/kg of diet (Edwards, 2002). However, bone ash was increased in this study. Differences in the effect of vitamin D_3 supplementation on P metabolism between studies may be caused by the level of P in the diet as suggested by Edwards (2002). Since the P level in the duck study of Rush *et al*. (2005) was relatively high, this may explain the absence of any vitamin D_3 effect on P metabolism. At this stage it seems worth further investigating the effects of vitamin D_3 sources on the utilisation of nPP and phytate P at a low level of P and Ca in the diet of ducks. It cannot be said whether the NRC (1994) recommendations can still be considered adequate for high growth and P utilisation in modern-type ducks.

3.5 Comparison of ducks and other poultry species with regard to P availability

Wendt and Rodehutscord (2004a) compared their P availability data with literature data for chickens. They concluded that values for inorganic P sources may not be very different between ducks and chickens. This could not be confirmed by Rodehutscord and Dieckmann (2005), who compared 3 wk old Pekin ducks, broiler chickens, turkeys and quails regarding their efficiency in utilising P from MCP. Ducks showed the highest marginal efficiency of P utilisation (96%), followed by turkeys (81%), quails (77%), and broilers (74%). Utilisation of P from the basal diet without P supplementation ranked differently and was 58% in broilers, 55% in quails, 46% in ducks, and 39% in turkeys. So far, only speculations can be made as to the reasons for these differences (Rodehutscord and Dieckmann, 2005). They may be related to species' differences in passage rate, gastro-intestinal pH, gut morphology, enzyme activities, etc. The activity of different digestive enzymes developed differently over time post hatch in ducks and chickens (Jamroz *et al.*, 2002). Presuming that the intestinal pH may be different, this could affect the solubility of inorganic P sources and related absorption. Applegate *et al*. (2005) found that Pekin ducklings had consistently higher jejunum and ileum weights and densities during the 7 d post hatch than turkeys. Comparisons of villus height and crypt depth showed a more rapid villus growth from hatch to 3 d of age. The authors concluded that the combination of increased intestinal growth and maturation through higher nutrient absorption allowed ducklings to achieve a 7 d BW that was almost twice as high as that of turkeys (290 vs. 150 g). It remains a subject of speculation whether these differences in morphology are relevant for P absorption. Comparative studies on localisation and capacity of phosphate transporters along the intestine of poultry are suggested. Intestinal enzyme activity, especially phytase, is addressed later in the following chapter. At this stage it can be concluded that differences in P availability exist between poultry species. It is possible to apply availability values for inorganic P sources obtained from chickens in feed compounding for ducks, and to stay on the safe side in doing so. Duck data, however, overestimate the availability of mineral P sources for chickens.

3.6 Phytase efficacy

Intestinal phytase activity was detected in brush border vesicles obtained from duodenal and jejunal mucosa cells of 18 d old Pekin ducks (Rush *et al*., 2005) with a method that had also been applied to detect intestinal phytase activity in chicken (Maenz and Classen, 1998). Alkaline phosphatase, which is involved in phytate hydrolysis, was also found in the small intestine mucosa of Pekin ducks (King *et al*., 2000). In one out of three studies with broiler chicken conducted by Applegate *et al.* (2003), intestinal phytate hydrolysis was correlated with intestinal phytase activity. Whether the intestinal phytase activity in ducks is high enough to be relevant for intestinal phytate hydrolysis is unclear. Studies by Rodehutscord and Dieckmann (2005) showed that differences between poultry species exist in the ability to utilise plant P.

Even when low-P diets with only marginal or without any phosphate and phytase supplementation are considered, P utilisation of Pekin ducks varied between 28 and 49% (Farrell *et al.*, 1993; Rodehutscord *et al.*, 2003; Wendt *et al.*, 2003; Wendt and Rodehutscord, 2004a,b). This is low, and consequently, supplemented microbial phytase can be seen as a promising tool to improve P utilisation in plant-based diets. Farrell *et al.* (1993) supplemented duckling diets at 4.1 to 5.3 g total P/kg with 850 U/kg *Aspergillus niger* phytase and found an increase in P utilisation from 35 to 49% in 2 to 10 d old ducks and from 52 to 59% in 10 to 17 d old ducks. Feed intake, growth, and tibia ash were improved due to phytase supplementation. Phytase improved precaecal P digestibility and tibia ash content in some studies, but growth was not always positively effected, depending on the level of P supply and age (Martin *et al.*, 1998; Orban *et al.*, 1999; Attia, 2003). Phytase from *Aspergillus niger* and *Peniophora lycii* caused a nonlinear increase in the aP content of duck diets when supplemented in a range between 150 and up to 2,000 U/kg (Wendt *et al.*, 2003; Wendt and Rodehutscord, 2004b). The plateau in P utilisation, which was approached with high supplementary levels, was almost twice as high as the P utilisation in the unsupplemented basal diet. Hence, microbial phytase has the potential to improve plant-P utilisation and reduce P excretion through reduced P supplementation in Pekin ducks like it does in other poultry species. However, the efficacy is highly variable (Figure 3). Relevant factors that determine phytase efficacy were not studied in detail with ducks. It is justified to assume that the generally known factors influencing phytase efficacy (diet type, P and Ca levels in the diet, etc.) are the same in ducks as in other species.

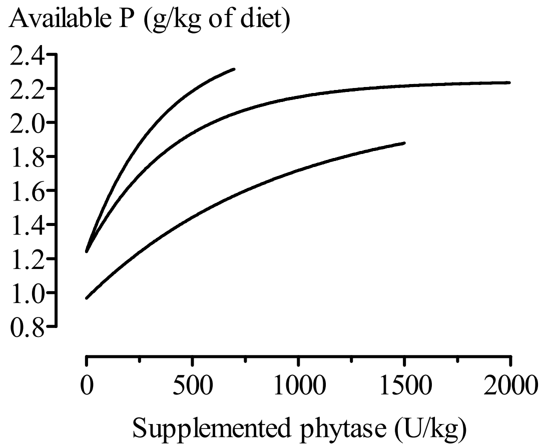

Fig. 3: Efficacy of microbial phytase, determined in dose-response studies with ducks fed different diets without inorganic P supplementation (data from Wendt *et al.*, 2003; Wendt and Rodehutscord, 2004b).

4 Consequences for the dietary P level and calculations

The concentrations of P that are needed in duck diets can be calculated based on the following assumptions:

1. The net requirement for aP depends on the P concentration in BWG and the inevitable P loss.
2. The concentration of aP in the diet depends on the net requirement for aP according to 1. and the feed/BWG ratio.
3. The concentration of total P in the diet depends on 2. under consideration of the chosen ingredients with their respective concentration and availability of P and, perhaps, the efficacy of a supplemented phytase.

The following general equation is suggested for calculating the necessary aP content in the diet:

$$aP_{Diet} = P_{BWG} / FCR + P_{IL} \quad [1]$$

with: aP_{Diet}: Concentration of available P in the diet (g/kg)
P_{BWG}: P concentration in gained BW (g/kg)
P_{IL}: Inevitable P loss (g/kg feed intake)
FCR: Feed conversion ratio (kg feed/kg body weight gain)

Based on Equ. 1, the resulting concentration of total P depends on the P concentration in the chosen ingredients, as well as on their respective availability:

$$tP_{Diet} = aP_{Diet} / aP \times 100 \quad [2]$$

with: tP_{Diet}: Concentration of total P in the diet (g/kg)
aP: P availability (%) as the weighted average of chosen ingredients

Table 2 gives an example of how the necessary dietary P levels can be modelled with a simple spreadsheet on the basis of Equ. 1 and 2. Individual factors were considered as discussed in the previous chapters. Calculations can easily be modified by choosing alternative values for the individual factors, for example the P concentration in BWG or the availability of the mineral supplement. It became clear that FCR is the most important variable in calculating the dietary P needs.

Table 2: Model calculations of the dietary P concentrations needed for high P retention of growing meat ducks

					aP of plant ingredients[4]			
					40%		55%	
Age	FCR	P_{BWG}[1]	aP in complete diet[2]	tP from pl. ingr.[3]	need for mineral P[5]	tP in final diet	need for mineral P[5]	tP in final diet
wk	kg/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg
1	1.2	5.0	5.2	4.0	4.0	8.0	3.3	7.3
2	1.4	5.0	4.6	4.0	3.3	7.3	2.6	6.6
3	1.7	5.0	3.9	4.0	2.6	6.6	1.9	5.9
4	2.1	4.9	3.3	4.0	1.9	5.9	1.3	5.3
5	2.5	4.8	2.9	4.0	1.5	5.5	0.8	4.8
6	3.2	4.7	2.5	4.0	1.0	5.0	0.3	4.3
7	4.2	4.6	2.1	4.0	0.6	4.6	0.0	4.0
8	6.0	4.5	1.8	4.0	0.2	4.2	0.0	4.0

[1] P concentration in body weight gain, according to chapter 2.1.
[2] Necessary concentration of available P in the diet according to Equ. 1, the value for inevitable P loss is 1 g/kg of feed intake according to chapter 2.2.
[3] Total P originating from the plant ingredients. A typical cereal grain-soybean meal diet is assumed.
[4] These values assume phytase-free plant ingredients (40%) or a supplement of microbial phytase (55%).
[5] Assumed availability of the supplemented mineral P source: 90% (see Fig. 2).

In growth trials with graded doses of MCP, Pekin ducks performed well at lower P levels than calculated in Table 2 (Orban *et al.*, 1999; Rodehutscord *et al*., 2003). Both studies, however, also showed that higher P levels for maximal P accretion or bone mineralization are needed than for high growth performance or feed efficiency. Rodehutscord *et al.* (2003) did not observe any disadvantage in accepting sub-maximal mineralization, but suggested conducting further studies before ultimately deciding whether P recommendations can be based on growth data or need to consider bone mineralization. Data in Table 2 are based on maximal mineralization values for the P content in BWG and exceed what is needed for a high growth rate.

Ducks fed according to Table 2 without phytase consume about 47 g total P in 7 wk. Inclusion of phytase in this example allows for a reduction in P use of about 10%. Total P retention is about 18 g per duck in 7 wk. Consequently, excreted P is about 29 g/duck without phytase, and reduced by 17% in phytase-supplemented diets. Since the contribution of the fattening period to the total feed intake is high, the most effective tool to reduce P efflux from duck enterprises is the continuous adjustment of the P content in the fattening phase. P excretion can be further reduced when sub-maximal bone mineralization in the fattening period is accepted.

Muscovy ducklings required 4.0, 2.2, and 1.8 g available P/kg of diet from hatch to 3 wk, 3 to 6 wk, and 6 to 10 wk of age (Leclercq and De Carville, 1979, cited by Elkin, 1987).

Only one study concerning breeder ducks was found. Using 2.7 instead of 5.4 g aP/kg of diet for breeder Pekin ducks resulted in significantly lower egg production, associated with reduced feed conversion ratio and increased mortality (Baéza and Leclercq, 1998).

References

APPLEGATE, T.J., ANGEL, R. and CLASSEN, H.L. (2003) Effect of dietary calcium, 25-hydroxycholecalciferol, or bird strain on small intestinal phytase activity in broiler chickens. *Poultry Science* **82:** 1140-1148.

APPLEGATE, T.J., KARCHER, D.M. and LILBURN, M.S. (2005) Comparative development of the small intestine in the turkey poult and pekin duckling. *Poultry Science* **84:** 426-431.

ATTIA, Y.A. (2003) Performance, carcass characteristics, meat quality and plasma constituents of meat type drakes fed diets containing different levels of lysine with or without a microbial phytase. *Archives of Animal Nutrition* **57:** 39-48.

BAÉZA, E. and LECLERCQ, B. (1998) Effects of feed restriction and phosphorus allowance during the laying period on the performances of breeder Pekin ducks. *Archiv für Geflügelkunde* **62:** 110-114.

BOCHNO, R., BRZOZOWSKI, W. and MURAWSKA, D. (2005) Age-related changes in the distribution of lean, fat with skin and bones in duck carcases. *British Poultry Science* **46:** 199-203.

DÄNNER, E., TIMMLER, R., BESSEI, W. and RODEHUTSCORD, M. (2005) Inevitable losses of phosphorus in growing male turkeys 8 and 12 weeks of age. *Archiv für Geflügelkunde, accepted for publication.*

EDWARDS JR., H.M. (2002) Studies on the efficacy of cholecalciferol and derivatives for stimulating phytate utilization in broilers. *Poultry Science* **81:** 1026-1031.

EECKHOUT, W. and DE PAEPE, M. (1994) Total phosphorus, phytate-phosphorus and phytase activity in plant feedstuffs. *Animal Feed Science and Technology* **47:** 19-29.

ELKIN, R.G. (1987) A review of duck nutrition research. *World's Poultry Science Journal* **43:** 84-106.

FAO (2005) Global Livestock and Health Atlas. http://www.fao.org/ag/aga/glipha/index.jsp, accessed June 3, 2005.

FARRELL, D.J., MARTIN, E., DU PREEZ, J.J., BONGARTS, M., BETTS, M., SUDAMAN, A. and THOMSON, E. (1993) The beneficial effects of a microbial feed phytase in diets of broiler chickens and ducklings. *Journal of Animal Physiology and Animal Nutrition* **69:** 278-283.

GFE (1999) Energie- und Nährstoffbedarf landwirtschaftlicher Nutztiere. 7. Empfehlungen zur Energie- und Nährstoffversorgung der Legehennen und Masthühner (Broiler). DLG-Verlag, Frankfurt a. M.

JAMROZ, D., ORDA, J., WILICZKIEWICZ, A. and SKORUPINSKA, J. (1998) Stickstoff- und Phosphorverwertung, wie auch Verdaulichkeit der Aminosäuren bei Verfütterung von Triticale und Enzymen an Hähnchen, Enten und Gänse. *Journal of Animal Physiology and Animal Nutrition* **79:** 123-134.

JAMROZ, D., WILICZKIEWICZ, A., ORDA, J., WERTELECKI, T. and SKORUPINSKA, J. (2002) Aspects of development of digestive activity of intestine in young chickens, ducks and geese. *Journal of Animal Physiology and Animal Nutrition* **86:** 353-366.

KING, D.E., ASEM, E.D. and ADEOLA, O. (2000) Ontogenetic development of intestinal digestive functions in White Pekin ducks. *Journal of Nutrition* **130:** 57-62.

LESKE, K. and COON, C. (2002) The development of feedstuff retainable phosphorus values for broilers. *Poultry Science* **81:** 1681-1693.

LIMA, F.R., MENDONCA, C.X., ALVAREZ, J.C., GARZILLO, J.M.F., GHION, E. and LEAL, P.M. (1997) Biological evaluations of commercial dicalcium phosphates as sources of available phosphorus for broiler chicks. *Poultry Science* **76:** 1707-1713.

MAENZ, D.D. and CLASSEN, H.L. (1998) Phytase activity in the small intestinal brush border membrane of the chicken. *Poultry Science* **77:** 557-563.

MARTIN, E.A., NOLAN, J.V., NITSAN, Z. and FARRELL, D.J. (1998) Strategies to improve the nutritive value of rice bran in poultry diets. IV. Effects of addition of fish meal and a microbial phytase to duckling diets on bird performance and amino acid digestibility. *British Poultry Science* **39:** 612-621.

NRC (1994) Nutrient Requirements of Poultry. National Academy Press, Washington, D.C.

ORBAN, J.I., ADEOLA, O. and STROSHINE, R. (1999) Microbial phytase in finisher diets of white pekin ducks: effect on growth performance, plasma phosphorus concentration, and leg bone characteristics. *Poultry Science* **78:** 366-377.

RODEHUTSCORD, M., ABEL, H., FRIEDT, W., WENK, C., FLACHOWSKY, G., AHLGRIMM, H.-J., JOHNKE, B., KÜHL, R. and BREVES, G. (2002) Consequences of the ban of by-products from terrestrial animals in livestock feeding in Germany and the European Union: alternatives, nutrient and energy cycles, plant production, and economic aspects. *Archives of Animal Nutrition* **56:** 67-91.

RODEHUTSCORD, M. and DIECKMANN, A. (2005) Comparative studies with three-week-old chickens, turkeys, ducks, and quails on the response in phosphorus utilization to a supplementation of monobasic calcium phosphate. *Poultry Science* **84:** in press.

RODEHUTSCORD, M., HAVERKAMP, R. and PFEFFER, E. (1998) Inevitable losses of phosphorus in pigs, estimated from balance data using diets deficient in phosphorus. *Archives of Animal Nutrition* **51:** 27-38.

RODEHUTSCORD, M., TIMMLER, R. and WENDT, P. (2003) Response of growing pekin ducks to supplementation of monobasic calcium phosphate to low-phosphorus diets. *Poultry Science* **82:** 309-319.

RUSH, J.K., ANGEL, C.R., BANKS, K.M., THOMPSON, K.L. and APPLEGATE, T.J. (2005) Effect of dietary calcium and vitamin D_3 on calcium and phosphorus retention in White Pekin ducklings. *Poultry Science* **84:** 561-570.

TIMMLER, R. and RODEHUTSCORD, M. (2001) Efficiency of different xylanase preparations in diets for pekin ducks. *Archives of Animal Nutrition* **55:** 315-332.

WENDT, P. and RODEHUTSCORD, M. (2004a) Investigations on the availability of inorganic phosphate from different sources with growing White Pekin ducks. *Poultry Science* **83:** 1572-1579.

WENDT, P. and RODEHUTSCORD, M. (2004b) Studies on the efficiency of two phytase preparations in Pekin ducks. In: *8. Tagung Schweine- und Geflügelernährung, Wittenberg*

(Germany); Universität Halle-Wittenberg, Halle (Saale), Germany; p 109-111. Available at http://www.te-halle.de/pdf/Tagungsband%20Teil%203.pdf.

WENDT, P., TIMMLER, R. and RODEHUTSCORD, M. (2003) Dose-response relationship between a supplemented microbial phytase and utilisation of phosphorus from a maize/soybean meal-based diet in Pekin ducks. *Archiv für Geflügelkunde* **67:** 193-197.

WPSA (1985) Mineral requirements for poultry - Mineral requirements and recommendations for growing birds. *World's Poultry Science Journal* **41:** 252-258.