Tables of composition and nutritional value of feed materials

Pigs, poultry, cattle, sheep, goats, rabbits, horses and fish

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Nutritional values for pigs

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Energy value

Introduction

The estimation of the energy value of feed ingredients for pigs requires several steps. The first one is the estimation of digestible energy (DE), calculated as the gross energy multiplied by the apparent faecal digestibility coefficient for energy (Ed). This coefficient varies according to the characteristics of the feeds but also with the live weight of the pig. Two main physiological statuses were considered: the 50-70 kg growing pig (the data can be applied to fast growing animals between 10 to 150 kg live weight) and the adult sow (the results can be used for both gestation and lactation) (Le Goff and Noblet, 2001). The energy losses in urine are calculated using the amount of nitrogen excreted in the urine and the losses in the form of gas from degraded cell walls; the latter energy loss differs between the two physiological statuses used to estimate DE. The metabolisable energy (ME) content is the difference between the DE value and the energy losses in urine and gas. The net energy (NE) value is estimated using the equations proposed by Noblet *et al.* (1994) which can be applied to both the growing pig and the sow.

Estimation of the digestibility of energy and nutrients

Growing pig

Energy digestibility (Ed) was estimated using prediction equations specific for each feed material. These equations used one or two chemical characteristics that were variable enough and able to discriminate between different feedstuffs. These equations were established using literature values and unpublished INRA data. However, for the majority of feed materials, there were not enough original digestibility values available for a single ingredient, and we had to group the data from feed materials having similar characteristics, such as botanical origin and anatomical structure. For example, the data from wheat and its by-products (bran, shorts, middlings, gluten feed, wheat distillery by-product, etc.) were combined (n = 52) and the Ed was calculated using cell wall constituents (crude fibre, NDF or ADF) as predictors. This method is illustrated in Noblet and Le Goff (2000) for wheat and maize products. Similar equations were established for the protein digestibility coefficient (Nd). These equations are reported by Noblet *et al.* (2003) and are available in digital format at www.inapg.fr/dsa/afz/tables/energie_porc.htm.

However, for several (families of) ingredients given in the tables, there were insufficient or no data in the literature or the results had been obtained using products that had very similar compositions (i.e., no variability). It was therefore impossible to establish specific prediction equations for Ed and Nd based on chemical composition. We used either the average values calculated from literature data - if the results were consistent - or, in the case of DE, values predicted by the following global equation (Le Goff and Noblet, 2001 and Noblet, unpublished; n= 77 diets):

$$DE = 0.2247\ CP + 0.3171\ EE + 0.1720\ Starch + 0.0318\ NDF + 0.1632\ Residue\ (RSD = 0.35)$$

DE is expressed in MJ/kg dry matter; CP (crude protein), EE (ether extract), NDF, starch and Residue are expressed in % dry matter. The Residue corresponds to the difference between the quantity of organic matter and the sum of the other constituents used in the equation.

For some feed materials, none of the previously described methods could be used so we chose a likely value. In all cases, Ed or DE content for each feed material were calculated using the chemical characteristics published in the tables. In addition, when several equations to predict Ed or Nd were obtained, the estimate provided by the most precise equation(s) was used.

The faecal digestibility coefficients for starch and sugars are considered to be equal to 100%, both in the growing pig and the adult sow. There is a paucity of data for faecal digestibility of fats (EEd) in the literature and the values found are sometimes incoherent and above all imprecise for products with less than 5% fat, as are the majority of the feed materials in the tables. Except for fat sources (oils and fats, see below), we decided to predict the digestible fat content (DEE) from an equation established by Le Goff and Noblet (2001) using 77 diets. EEd corresponds to the ratio between DEE and the fat content (x 100). The following equation was used:

$$DEE = 0.82\ EE - 0.02\ NDF - 0.7\ (RSD = 0.33)$$

where DEE, EE and NDF are expressed in % dry matter. This equation gives very low EEd values (which can even be negative) for products with low levels of fat.

For numerous reasons, there are few reliable data concerning cell wall digestibility in the pig. Therefore, it was not possible to estimate directly the digestibility of this fraction. The indirect method used was to estimate the faecal digestibility coefficient of organic matter (OMd) or the content of digestible organic matter (DOM). Firstly, a residue (Res) which corresponds to the difference between organic matter and the sum of crude protein, ether extract, starch and sugars was calculated. Secondly, a digestible residue (DRes), equal to the difference between the DOM content and the sum of DCP, DEE, starch and sugars (calculated according to the methods described above) was also calculated. The components Res and DRes are theoretically equivalent to respectively the cell walls and the digestible cell walls. However, the values are calculated by difference and not measured directly. OMd was estimated using the following equation (Noblet, personal communication, n = 270 diets):

$$OMd = 7.0 + 0.955\ Ed - 0.05\ DCP - 0.03\ DEE\ (RSD = 0.4)$$

The following equation has the same precision as the previous one:

$$OMd = 7.9 + 0.915\ Ed + 0.031\ (Starch + Sugars)\ (RSD = 0.4)$$

OMd and Ed are expressed in %; DCP, DEE, starch and sugars are expressed in % of dry matter.

For all feed materials with high fat content (oils and fats), the EEd, Ed and OMd were assumed to be 85%, both in the growing pig and the adult sow. This value is the same as the average of the literature values and does not take into account the potential (but unlikely) differences in digestibility associated with the degree of fatty acid unsaturation. However, it cannot be used for products rich in free fatty acids (e.g. acid oils) for which the EEd (and the Ed) are much lower. Finally, the Ed of synthetic amino acids was fixed at 100% and the DE value was therefore considered to be the same as the gross energy concentration of the pure amino acid.

Adult sow

It is stated in the literature that energy digestibility is higher for adult sows than for growing pigs. This effect depends on the quantity and botanical origin of cell walls and it clearly justifies the choice of two distinct energy values for feedstuffs (Le Goff and Noblet, 2001). However, due to a shortage of literature data, energy digestibility for the sow cannot be estimated by regression, unlike the growing pig. In addition, the few data available do not necessarily correspond with the feed materials defined in the tables. The approach described by Le Goff and Noblet (2001) in which the DE content for the sow is estimated using the DE content measured or estimated in the growing pig was possible for some families of feed materials (wheat, maize and soybean; Noblet and Le Goff, 2000 and Le Goff and Noblet, 2001). However, such equations were not available for all the feed materials in the tables. In addition, there was a risk that a bias would be introduced if the same equation were used for all feed materials.

A further analysis of the data used in the publication of Le Goff and Noblet (2001) shows that the difference in DE content between the sow and the growing pig is directly proportional to the level of indigestible organic matter in the growing pig. In their study, concerning 77 diets, an increase in the DE concentration per g of indigestible organic matter in the growing pig (DEdiff) was on average 4.2 kJ per g. This extra 4.2 kJ of DE is associated with an additional supply of 0.195 g of DOM, made up of 0.058 g DCP and 0.137 g DRes. However, a comparison of digestibility measurements in the sow and growing pig shows that the DEdiff varies according to the (families of) feed ingredients (Noblet *et al.*, personal communication). For example, DEdiff is 2.9 kJ for wheat products compared to 7.5 and 8.0 kJ for soybean and maize products, respectively. The data obtained by INRA for about 50 feed materials (Noblet *et al.*, unpublished) made possible the estimation of DEdiff for all the products in the tables (values vary between 0 to 8.4). It has also allowed the calculation of the differences in DE, DOM, DCP and DRes contents between the adult sow and the growing pig using the level of indigestible organic matter in the growing pig (as has been previously defined). It was assumed that the amount of DOM per kJ (0.047 g/kJ) and the repartition of the surplus DOM between DCP and DRes were constant whatever the value of DEdiff. The levels of DE, DOM, DCP and DRes in the adult sow were then obtained by adding the calculated differences to the levels of DE, DOM, DCP and DRes estimated in the growing pig. It was assumed that the digestibility coefficients for fat, starch and sugars are identical for the growing pig and the adult sow.

Estimation of ME content

As indicated in the introduction, the energy losses in urine (Euri) and in fermentation gases (methane; Egas) were taken into account in the calculation of the ME content of feed materials. An analysis of the data obtained in 50-70 kg growing pigs and in the adult sow (n = 610; Noblet, personal communication) showed that Euri (MJ/kg ingested dry matter) depends on the quantity of nitrogen measured in the urine (Nuri; g/kg of ingested dry matter). The prediction equations are:

Growing pig: $\text{Euri} = 0.19 + 0.031\ \text{Nuri}$ (RSD = 0.05)

Adult sow: $\text{Euri} = 0.22 + 0.031\ \text{Nuri}$ (RSD = 0.05)

The quantity of nitrogen excreted in urine is directly proportional to the difference between the daily supply and the capacity of the pig to fix nitrogen in the form of protein. We can assume that for most stages of pig production, when the protein supply has a correct amino acid balance and meets the animal's requirements, close to 50% of digestible nitrogen is fixed or the quantity of nitrogen found in the urine represents 50% of digestible nitrogen. This assumption was applied to each feed material and for the level of DCP (N x 6.25) estimated according to the methods described above.

The quantity of energy lost in the form of gas (Egas) was calculated using the quantity of fermented cell walls. This was considered to be equal to the DRes value obtained in the nutrient digestibility method. The compilation of data obtained in respiration chambers (Le Goff, 2001) allows the estimation of Egas: 0.67 and 1.34 kJ per g of DRes in the growing pig and the adult sow, respectively.

For feed materials containing neither cell walls nor crude protein (oils and fats), this method produces a ME value which is very close to that of DE, as observed in animal experiments. The synthetic amino acids generally represent a limiting factor for nitrogen retention and it can be supposed that the retention coefficient for the nitrogen supplied by these amino acids is higher than that for total nitrogen. We have estimated it to be 65% when calculating their ME values.

Estimation of NE content

The NE content of feedstuffs has been estimated using equations established by Noblet *et al.* (1994) with 61 diets. Three equations were preferentially used:

$$\text{NE2} = 0.121\ \text{DCP} + 0.350\ \text{DEE} + 0.143\ \text{Starch} + 0.119\ \text{Sugars} + 0.086\ \text{DRes}\ (\text{RSD} = 0.25)$$

$$\text{NE4} = 0.703\ \text{DE} + 0.066\ \text{EE} + 0.020\ \text{Starch} - 0.041\ \text{CP} - 0.041\ \text{CF}\ (\text{RSD} = 0.18)$$

$$\text{NE7} = 0.730\ \text{ME} + 0.055\ \text{EE} + 0.015\ \text{Starch} - 0.028\ \text{CP} - 0.041\ \text{CF}\ (\text{RSD} = 0.17)$$

NE, ME and DE are expressed in MJ/kg dry matter. The chemical constituents are expressed in % dry matter.

Equation NE2 is actually a variant of the equation NE2 proposed by Noblet *et al.* (1994), as the "Weende" analysis was not used here to define the values of digestible elements. In practice, the NE value given in the tables is the average of the three NE values obtained using the above equations and applied to the feed materials for which the chemical characteristics are given in the tables. The values of digestible nutrients or DE or ME were obtained using the methods described above. For sources of fat (oils and fats) and feed materials that contain practically only starch (maize starch), equation NE2 was used to calculate the NE value. In the case of synthetic amino acids, it was assumed that the efficiency of ME use was 85% for the fraction fixed in body protein (65% of DE) and 60% for the fraction which was deaminated (35% of DE).

Conclusion

The approach proposed for the calculation of the energy values of feedstuffs for pigs generates six energy values appropriate to the physiological status of the animal - growing pig and adult sow - according to three different systems (DE, ME and NE)

The NE system should be preferred, because it results in the estimation of an energy value which is the closest to the "true" value and thus allows the formulator to differentiate more precisely between feed materials when calculating diets. Finally, it should be noted that the NE value of a feedstuff is highly dependent on its DE and ME values, which are themselves dependent on the chemical characteristics of the feed, the animal that consumes the feedstuff and the technology used (milling, granulation etc...) to produce the diet. The values given in the tables are principally for ground feeds, rapeseeds being the sole exception: the table values are given for pelleted rapeseed as the non-pelleted form has a very low digestibility. In general, pelleting improves energy and nutrient digestibilities. However, literature data are insufficient to propose, for all the materials used in pig feeding, energy values that take into account the different types of processing, in particular pelleting.

Nutritional value of proteins and ileal digestibility of amino acids

The nutritional availability of amino acids (AA) can be estimated by measuring their digestibility at the end of the small intestine, or ileum. Indeed, in the large intestine, microorganisms can metabolise some undigested amino acids, which prevents them from appearing in the faeces. Therefore "ileal" digestibility is used. The data for apparent and standardised ileal digestibility given in the tables are derived from experiments started in the early 1980's by Adisseo, by ITCF (with the help of Ajinomoto Eurolysine) and by INRA (Rennes). These data were collated between 1996 and 1999 and published as a CD-ROM (AFZ *et al.*, 2000).

Ileal digestibility can be determined in pigs fitted with an ileal cannula, after measuring the concentrations of an indigestible marker, or in pigs with an ileo-rectal anastomosis (IRA), after collecting the totality of the ileal output. The data presented in the tables were obtained using the termino-terminal ileo-rectal anastomosis technique, validated by Laplace *et al.* (1994), where the large intestine is completely isolated. The way in which ileal digestibility is expressed depends on how the endogenous losses have been taken into account in the calculations (Sève, 1994). Both "apparent" and "standardised" digestibilities are given in the tables.

Apparent digestibility

Apparent digestibility ignores the endogenous or exogenous origin of the undigested nitrogen (N) or AA. The quantities of undigested N or AA are considered proportional to the quantity of dry matter ingested for the feed material being studied. If the diet used for the measurements contains other ingredients, it is necessary to estimate the quantities of undigested N or AA generated by the dry matter of these ingredients. The quantities of undigestible N or AA effectively associated with the tested feed material can be calculated "by difference". This applies when the material under test is substituted into a basal diet, which can contain protein or be protein-free, and the apparent digestibility can then be estimated as if the diet was only composed of the source of proteins being tested.

Therefore, in the case of protein-rich feed materials diluted with protein-free ingredients (starch, sugar, vegetable oil etc...) so that they are the only source of protein in the diet, the contribution of these ingredients to the indigestible fraction needs to be subtracted from the apparent undigestible value. Without this correction, the quantities of N or AA that are apparently digested for protein-rich feed materials are underestimated. In addition, the values are not additive for feed materials having a protein content low enough to make dilution unnecessary. Most of the values for apparent digestibility published to date and measured in this way are not corrected and are therefore not additive.

Standardised digestibility

The concept of biological value proposed by H. H. Mitchell in the 1920's distinguished between nitrogen losses due to dietary proteins from endogenous losses due to maintenance requirements. It is now known that these endogenous losses can vary depending on the composition of the protein source. This is why it is necessary to consider separately the basal endogenous losses. These basal losses are independent of the composition of the feedstuff being studied and are not proportional to the quantity of protein ingested. However, they can be proportional to the total quantity of dry matter ingested (figure 3)

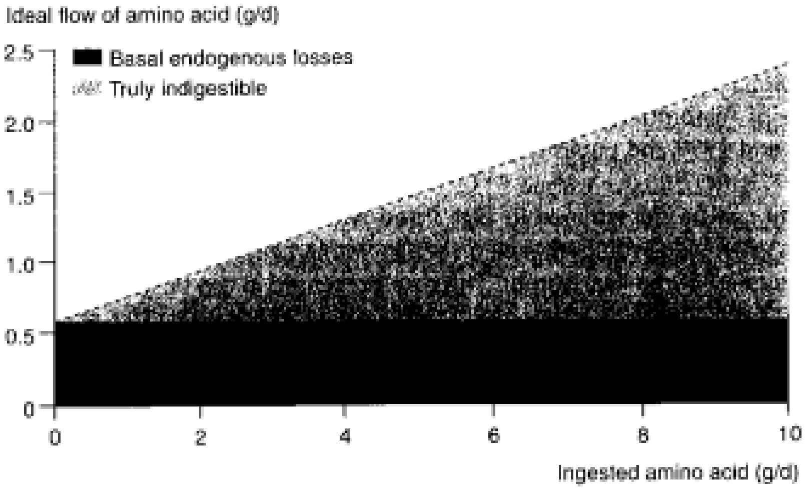

Figure 3. Effect of the quantity of ingested amino acid on the ileal flow of amino acids, at a constant level of dry matter intake.

By subtracting these losses from the measured indigestible fraction, the true digestibility, as defined by H. H. Mitchell, can be calculated. It is independent of the metabolic level of the animal. In the case of measurements performed by diluting a protein source with protein-free ingredients, it is possible to calculate, from a variable apparent digestibility, a true digestibility independent of the level of the feedstuff in the diet (figure 4).

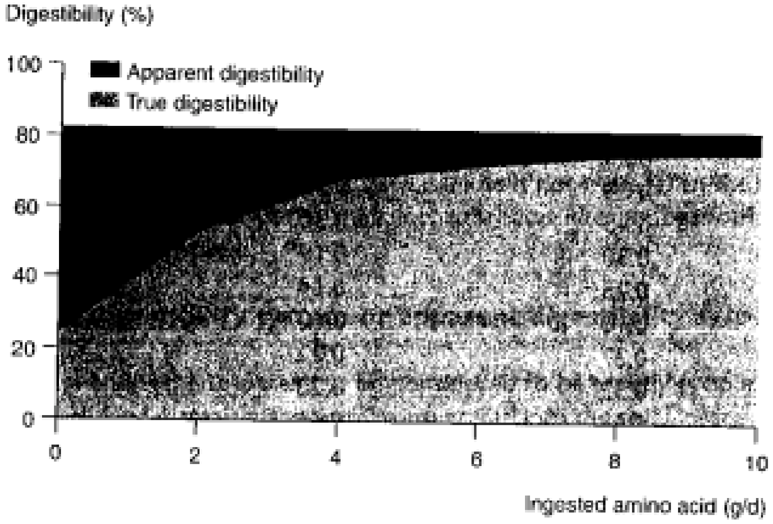

Figure 4. Effect of the quantity of ingested amino acid on apparent digestibility, at a constant level of dry matter intake.

Furuya and Kaji (1991) have shown that, contrary to the values of apparently digestible AA (not corrected), the values of "truly" digestible AA are additive. This is explained by the fact that, as is the case for the quantities of "truly" undigestible AA, they are strictly proportional to the protein content of the feed material being studied. To avoid confusion with the concept of "real" digestibility, it is now preferable to use the term "standardised digestibility".

The standardised ileal digestibility values (SID) depend on the estimation of basal endogenous losses of N or of each AA. If the animals do not receive the diet for a long period, the use of a protein-free diet is the most appropriate method to measure these losses. It has been shown that the basal endogenous losses, when measured using protein-free diets of similar composition (Sève *et al.*, 2000), depend on the laboratory where they were measured.

Calculations

The tables provide the averages of measurements taken at three different sites. Each feed material was usually the only protein source in the diet. For each individual value of true digestibility, the apparent ileal digestibilities of the diet (AID in %) were estimated by using the basal endogenous losses characteristic of each site (EndobDMI) expressed in g/kg of ingested

Table 1. Basal endogenous losses (g/kg ingested dry matter) in the three laboratories that produced the digestibility data used in the tables.

Laboratory	A	B	C
Crude protein	8.66	7.22	9.67
LYS	0.29	0.24	0.41
THR	0.33	0.27	0.39
MET	0.08	0.05	0.13
CYS	0.14	0.11	0.17
TRP	0.09	0.09	0.17
ILE	0.26	0.18	0.33
VAL	0.34	0.25	0.48
LEU	0.45	0.30	0.53
PHE	0.30	0.19	0.33
TYR	0.25	0.14	0.28
HIS	0.16	0.10	0.13
ARG	0.27	0.22	0.35
ALA	0.32	0.28	0.50
ASP	0.54	0.41	0.72
GLU	0.78	0.52	0.92
GLY	0.39	0.47	0.45
SER	0.35	0.25	0.38
PRO	0.54	ND	0.53

ND = not determined

dry matter (table 1) and the AA content of the diet (AADietDM), expressed in % of dry matter. The following equation was used:

$$\text{SID} = \text{AID} + (\text{EndobDMI}_{\text{site}} \times 10/\text{AADietDM}) \qquad \text{equation 1}$$

The protein-free ingredients used to dilute the feed materials were similar to those used to estimate basal endogenous losses. The corrected AID values given in the tables were calculated using the SID and AA content of the feed material (AAFMDM, in % of dry matter) using:

$$\text{Corrected AID} = \text{SID} - (\text{EndobDMI}_{\text{site}} \times 10/\text{AAFMDM}) \qquad \text{equation 2}$$

This corresponds to the following relationship between the corrected apparently digestible AA content (Corrected AIDC) and the standardised digestible AA content (SIDC), both expressed per kg dry matter of the feed material:

$$\text{Corrected AIDC} = \text{SIDC} - \text{EndobDMI}_{\text{site}} \qquad \text{equation 3}$$

Use of the data in formulation

The basal endogenous losses are independent of the nature of the constituents of the feed materials. They represent an expense of body nitrogen that must be covered by the diet. The standardised supply of digestible amino acids allows this requirement to be taken in account. In contrast, the corrected apparent undigestible component of the feed material simply includes the basal loss without any differentiation from the feed protein loss. Therefore, the requirement expressed in standardised digestible AA must exceed the requirement expressed in corrected apparent digestible AA, of a value at least equal to the basal endogenous loss. There are three conditions for the least cost formulation to lead to the same result whatever the mode of expression, 1) the correction of the apparent digestibility (see above), 2) the hypothesis of proportionality between basal endogenous losses and ingested dry matter, 3) the assumption that the requirement for net synthesis of the basal loss is not higher than the loss itself, meaning 100 % efficiency of digestible AA for their incorporation into endogenous protein, i.e., zero metabolic cost for this protein.

Standardised digestibility system or apparent digestibility system?

As long as basal endogenous losses can be considered to be strictly proportional to ingested dry matter for all feed materials, they can be integrated into the total losses attributable to the dry matter of the feed material. This means that the digestible AA contents, be it corrected apparent or standardised, can be used indifferently and converted from one to the other with equation 3. However, some factors related to animal feeding behaviour, physiological characteristics (live weight, age etc...) (Hess and Sève, 1999) and environment (Sève *et al.*, 2000), can significantly modify this proportionality and introduce a bias in the estimation of apparent digestibility. In addition, within the standardised digestibility system, it is possible to take into account the metabolic cost of the basal endogenous loss, which is impossible within the apparent digestibility system. Therefore, the use of the concept of standardised digestibility appears to be more pertinent than that of apparent digestibility.

Phosphorus digestibility

The principle used for the calculation of the "phosphorus value" of a feed material is its digestible phosphorus concentration. It is calculated by multiplying the total phosphorus concentration by the apparent faecal digestibility coefficient of phosphorus. The digestibility coefficients were obtained in most cases from published or unpublished results produced over the last ten years by Arvalis - Institut du Végétal (formerly ITCF, Institut Technique des Céréales et des Fourrages) using pigs weighing approximately 45 kg (Barrier-Guillot *et al.*, 1996; Chauvel *et al.*, 1997; Skiba *et al.*, 2000). We have also used additional data from the literature based on the same concept (Jongbloed *et al.*, 1993; Jongbloed *et al.*, 1999). In some cases, due to the lack of recent reliable references, the digestibility coefficient can be absent from the tables.

In some feed materials, the presence of endogenous phytase causes a problem concerning the additive nature of digestible phosphorus values calculated in this way. The endogenous phytase found in a feed material can increase not only the digestibility of its phytate phosphorus but also the digestibility of the phytate phosphorus found in the other diet ingredients. This is why two values for apparent faecal digestibility are given for feed materials with a significant endogenous phytase activity (wheat and its by-products, rye, barley and triticale). The first value (Pd) corresponds to the feed material when phytase has been denatured, e.g. by heating. The second value ($P_{Phy}d$), which is higher, corresponds to the same feed material in cases where it is processed in a way that does not affect phytase activity, milling for instance. Only the first value allows the calculation of additive digestible phosphorus concentrations; the second value only gives an indication of phosphorus digestibility.

Two steps are therefore necessary in order to estimate the concentration of apparent digestible phosphorus in a diet. In the first step, apparent digestible phosphorus is estimated in a diet made up of feed materials where the phytase has been denatured. This is done by multiplying the phosphorus content of each feed material by its apparent faecal digestibility. The second step is to take into account the phytase activity of the diet by adding to the previously calculated value an estimation of the quantity of apparent digestible phosphorus released by the phytase present in the diet. The second step is problematic for several reasons. Firstly, the phytase activity in a given feed material is variable. Secondly, the phytase present in a diet is sensitive to any technological treatments it has undergone. Finally, in the case of plant phytase, the estimation of a relationship between phytase activity and the level of apparent digestible phosphorus remains difficult in the light of present knowledge.

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