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Statement on energy evaluation of feeds for pigs based on metabolisable energy versus net energy

Stellungnahme zur energetischen Futterbewertung beim Schwein auf Basis Umsetzbarer Energie versus Nettoenergie

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Summary

This statement is a comprehensive presentation of the scientific arguments and aspects relevant to practical feeding and formulation of rations and compound feeds which are important in evaluating feeds for pigs on the basis of metabolisable energy (ME) and net energy (NE).

The ME indicates the capacity of a feed to provide energy for the animal's metabolism. The NE additionally includes the nutrient-specific heat losses occurring in the metabolism and represents the retained energy (RE) in the growing animal. However, because the extent of these losses is not constant, especially for protein, and the energy requirements for basal metabolism, gestation, thermoregulation and physical activity must be expressed as equivalents to RE, this leads to problems or inaccuracies. The RE as part of performance prediction is therefore only partly successful with a NE system. Only by knowing the composition of the ration, especially its protein and amino acid contents, and the animal's characteristics, notably protein deposition capacity, is it possible to predict growth, body composition and nutrient excretion.

Extensive calculations carried out in cooperation with a large feed manufacturer have shown that optimisation of compound feeds based on NE versus ME does not lead to a reduction in cost or to a decrease in protein concentration of the feed. Any specific NE system also has the disadvantage of incompatibility with other NE systems, whereas the NE values of different NE systems can generally be calculated from the ME value. A major problem of using NE values is that they cannot be verified experimentally due to the great effort associated with respiration studies. In contrast, ME values can be determined using digestibility studies complemented by urine collection. New findings on nutrient utilisation efficiency and energy requirements can be inserted into recommendations for energy supply more easily and more quickly in a ME system than in NE systems, because in the latter the feed values and hence the feed tables would need to be amended.

It is therefore not advisable, either from a scientific point of view or in the interests of agricultural practice, to convert from ME to one of the existing NE systems. According to current knowledge, ration formulation based on ME is to be regarded as best practice.

1. Introduction

Precise determination of the energy supply capacity of feeds is crucial because the economic value of most feeds depends largely on the energy content and animal performance is strongly influenced by the energy supply. In feeds with low fat content, it is mainly the fat content and the digestibility of the fibre fractions which determine the variation in energy feed value, since proteins, starch and sugars generally have high precaecal digestibility (pcd). Losses occurring during fibre fermentation (in the form of methane, fermentation heat and microbial matter) also reduce the energy value of fibre-rich

feeds. Menke (1987) postulated that the task of energy evaluation of feeds is to estimate the losses mainly caused by characteristics of the feed. According to this postulate, losses via methane production and urinary excretion must be taken into account in addition to losses via faecal excretion (metabolisable energy, ME). If the metabolic heat produced due to nutrient supply is also included, this leads to net energy (NE). The purpose of this statement is to present the state of the art with regard to energy evaluation of feeds for pigs in Germany and to identify the reasons which led to the decision to carry out evaluation at ME level. Possible benefits and limitations of evaluation at NE level are also presented, together with associated drawbacks. This statement is an extension of the arguments previously published by the Committee of Nutrient Requirement Standards (Ausschuss für Bedarfsnormen, AfBN) of the Society of Nutrition Physiology (Gesellschaft für Ernährungsphysiologie, GfE) in December 2015 in the form of a press release¹. The text is based on statements by the GfE (2008, chapter 2) and on publications by Susenbeth (2005, 2010 and 2016) which deal with some aspects in more detail.

2. Evaluation at the level of metabolisable energy

The guiding principle adopted by the AfBN was to define energy feed value as the potential to provide energy for the animal's metabolism, and to calculate it from the concentrations of digestible nutrients (GfE, 2008). This necessarily leads to evaluation at ME level. However, predicting performance and hence retained energy (RE) cannot be a primary task of energy evaluation of feeds. This is because energy utilisation is also affected by amino acid supply, performance potential and the type of performance of the animals. As a result, performance can be predicted only to a very limited extent based solely on the characteristics of a feed (see the comments below).

The equation for calculating the ME content is (GfE, 2008):

$$\text{ME} = 20.5 \text{ DXP} + 39.8 \text{ DXL} + 17.3 \text{ ST} + 16.0 \text{ SU} + 14.7 \text{ DOR} \text{ (kJ or g/kg dry matter [DM])},$$

where DXP stands for digestible crude protein, DXL digestible crude lipids, ST starch, SU sugar, DOR digestible organic residue (DOR = DOM - DXP - DXL - ST - SU; DOM = digestible organic matter). This formula is based on extensive studies conducted by the Rostock research group (Jentsch et al., 2001). Only the factor for DOR has been modified compared with the original equation. This takes account of methane losses and fermentation heat. This equation is very robust and reliable in its application since the factors are almost identical to the theoretical values. The factor 20.5 for DXP corresponds to a ME value for protein where protein is utilised efficiently in the metabolism, i.e. urinary N excretion is low. Of note, the factors for ST and SU refer not to the digestible fractions but to the total content in the feed; however, due to their generally very high pcd, these factors are almost identical to the gross energy value.

The inclusion of DOR, whereby the fibre fraction and other non-starch polysaccharides (NSP) are determined not by analysis but by calculation, leads to a substantial advantage in terms of reliability when applying the equation². Analytical errors, especially in the case of carbohydrate fractions, have only a marginal effect on the calculated ME value since any over- or under-estimation of nutrient levels is quantitatively offset by DOR. The factors for the three fractions DOR, ST and SU do not differ considerably, so the effect of an analytical error on the ME value of the feed is marginal. For example, if the starch content is under-analysed by 5 percentage points, the DOR content increases by 5 percentage points. Despite this substantial analytical error, the resulting error for determination of the ME content of the feed is only $(17.3 \text{ kJ/g} - 14.7 \text{ kJ/g}) \cdot 50 \text{ g} = 0.13 \text{ MJ/kg DM}$. The GfE (2008) points out that applying the formula to feed materials containing substantial levels of pectins or alcohols, for example, can lead to false estimations. In these cases the accuracy of calculation can be

¹ http://www.gfe-frankfurt.de/download/GfE_Nettoenergie_Schwein.pdf.

² An organic residual fraction is also included in other authors' equations (Susenbeth, 2005). Note, however, that this fraction is defined or calculated differently in the respective equations.

improved if the quantity and energy value of such nutrients are taken into account separately and the nutrient fraction concerned is reduced accordingly if necessary³. The same applies to feeds in which the starch has a low pcd; post-ileally digested starch is attributed to DOR.

The question remains of whether all losses associated with fermentation are covered to the necessary extent by using a factor of 14.7 for DOR, which at first appears fairly high and is only 2.6 units lower than that for starch. These 2.6 kJ/g only cover the losses via fermentation heat and methane production. The microbial mass produced during fermentation is another, greater source of loss and amounts to more than 20 % of the fermented energy. However, this loss is not covered by the factor for the energy value of DOR, because in digestibility studies the microbial matter is contained in the crude protein fraction as well as in other fractions, and hence it is considered via faeces analysis. It would therefore be incorrect to conclude from the formula that 1 g of fermented fibre provides 14.7 kJ ME; rather, according to this formula too, the energy value is below 11.2 kJ ME/g if all fermentation-related losses, including microbial matter, are covered solely by the factor for DOR.

The ME equation of GfE (2008) can be used very successfully to describe the energy provided for the metabolism by the feed. There is a slight limitation due to the variability of urinary energy loss. However, the level of urinary energy losses cannot be attributed to the feed materials because these losses are mainly a result of protein content and quality in the total ration, which is determined by the pcd and pattern of the amino acids, as well as by the animals' protein deposition.⁴

3. Performance prediction based on metabolisable energy

Energy evaluation of feeds cannot be carried out separately from determining requirements or predicting performance (Menke, 1987). It is not the task of an energy evaluation to predict performance. However, energy feed value must be defined in such a way that it can be used as one of the determinants for performance prediction. For example, the utilisation factors ($k = RE/ME$) obtained by Jentsch et al. (2000a) and confirmed by comprehensive experiments can be used to predict energy retention (RE) during growth. For starch, protein and fat, the factors are 0.757, 0.623 and 0.859 respectively. If starch equals 100 %, protein and fat are 82 % and 113 % respectively⁵. To simplify in practice, however, a mean k_{pr} value of 0.72 to 0.74 and a k_l value of 0.72 (Susenbeth, 1996⁶; GfE, 2008) can be used, based on the ME of the ration, to predict the energy retained in the body or transferred into milk; here, differences between nutrients in terms of utilisation efficiency are not considered.^{7,8} This means that predicting RE based solely on ME, without knowing the respective

³ This procedure is followed by the CVB (2016) in Formula F.V09.

⁴ This problem of variability in urinary energy excretion applies equally to NE. A way to improve the accuracy of the ME value (and hence of the NE value) of a ration and avoid this uncertainty is to include the animal's protein utilisation, which is the main cause of differences in urinary energy excretion. A proposal for such a calculation has been worked out (A. Susenbeth, unpublished) in which two energy values are used for protein: a higher value for protein which is used for protein deposition and has the maximum protein utilisation of the ideal protein, and a much lower value for protein which exceeds the minimum requirements (i.e. the minimum supply of precaecally digestible crude protein; see Table 4.9; GfE, 2008) and where the corresponding nitrogen is completely excreted via the urine.

⁵ The use of the utilisation coefficients given by Noblet (2006) leads to divergent results, as these coefficients differ considerably from those of Jentsch et al. (2000a).

⁶ The higher k_{pr} value given here compared with the original publication results from the use of the energy values of 23.8 kJ/g crude protein and 38.7 kJ/g crude lipids.

⁷ The k_p value (= 0.56) and k_f value (= 0.74) (GfE, 2008) must be differentiated from the different energy utilisation of the individual nutrients. These values indicate the efficiency of ME utilisation for energy retention as protein or fat, irrespective of the nutrient concentration of the ration, i.e. they focus not on the origin of the energy but on its target, and therefore apply to rations which have common levels of protein, fibre and lipids.

nutrient levels, necessarily entails a degree of inaccuracy. This is the crucial fact which is used as an argument to support the necessity of feed evaluation at NE level. However, this inaccuracy (constant k value, no consideration of nutrient differences) is very small for a situation where protein supply meets requirements. The same is true for fat: energy utilisation increases by only 0.001 per percentage point of fat in the ration.

Assuming constant⁹ ME utilisation independent of nutrient composition, the accuracy of the RE calculation actually decreases slightly only for rations with higher fat contents and excess protein levels, and NE might have an advantage in this case. For a more precise estimation of RE, which also requires knowledge of the animal's protein deposition and the content and quality of protein in the ration and also takes account of housing conditions if necessary, evaluation of the energy supplied by the feed on the basis of ME is not an obstacle; rather, it can and should be done on this basis. For the reasons mentioned before, the argument that a more accurate estimation of energy retention can be obtained with NE is irrelevant for the purposes of practical ration formulation and feeding.

4. Energy evaluation at the level of net energy

The central concern of energy evaluation of feeds at NE level is, as mentioned above, the prediction of RE while considering the different *energy utilisation of the individual nutrients*. A critical assessment of NE therefore has to be done firstly with this objective in mind:

1. The NE indicates the RE (mainly as fat deposition), which is calculated from the ME content of the individual nutrients and their utilisation factors. However, the RE value derived in this way is associated with a fundamental problem which is especially apparent in the case of protein. It must be assumed that the **utilisation efficiency of ME from protein** is not constant and is different for protein deposition than for pure energy use. The energy value of protein can therefore be influenced by factors which are not caused by characteristics of the feed and hence are unknown in the evaluation process. Only by knowing the total ration, protein quality and animal's performance is it possible to predict the protein deposition and thus the efficiency of protein utilisation. For example, the Dutch institute Schothorst Feed Research (2016) reiterates that the main limitation of NE systems is that post-absorptive nutrient use cannot be considered and that consequently the use of a uniform energy value for protein does not take account of its different potential uses. Indeed, Boisen (2007), who developed the Danish system of Potential Physiological Energy, concludes that NE is not a suitable basis for feed evaluation. He has considered the criticism raised previously by other authors, namely that NE applies only to a specific production and that the animal's response in the form of RE is also inadequate as a precise measure of feed energy value because influences stemming from the animal itself lead to variability in such a feed energy value.

The inability to define a generally valid energy value for protein due to this variability in protein utilisation supports evaluation at ME level, since this problem does not need to be considered - or can be left open - in feed evaluation based on ME. Two major NE systems, the Rostock feed evaluation system (Beyer et al. 2003, based on Jentsch et al., 2001) and the French system (INRA, 2004, based on Noblet et al., 1994), obviously give the energy value of protein for sole energy use. In the future, if proven specific utilisation factors were available for the respective protein use (protein deposition or energy use), they could be included in NE systems only with difficulty because the feed evaluation might have to be changed and feed tables revised. In the case of ME, however, they would be relatively easy to include in determining requirements or predicting performance. Besides the variability in utilisation, there are additional conceptual problems with evaluation at NE level:

⁸ A k_{pf} value of 0.73 to 0.74 is also obtained by INRA (2004; equation NE7) for an average ration composition.

⁹ See footnote 7.

2. The established NE values are above all only valid for performance in the form of energy retention during growth. **Milk production** does show a similar efficiency of ME utilisation. However, in a NE system, a separate utilisation factor would have to be introduced for lactose production. The problem is even more apparent if **gestation** requirements have to be determined: Since ME utilisation for gestation is much lower than for growth, the gestation requirements - given as NE for growth - are several times greater than the actual energy retention in foetuses and adnexa. A formal conversion is possible, but difficult to communicate.

3. There is an even greater problem with regard to **maintenance** requirement, since this also has to be given as RE. After all, even in intensively growing animals, around one third of total energy requirement is allocated to maintenance. It is known not only that utilisation efficiency in maintenance differs from that in growth, but also that the ratios between utilisation factors for nutrients differ (Chudy and Schiemann, 1969; Blaxter, 1989; Jentsch et al., 2000a).

4. Requirements for **physical activity** and **thermoregulation** *can only* be given in ME, since the ME expended on them is wholly converted into heat and NE values for such requirements do not exist. The heat production is greater than the necessary requirements expressed as NE. Such requirements which are not allocated to maintenance and growth can amount to 15 % of total requirements under commercial housing conditions for growing pigs (Naatjes et al., 2014). It has also been observed that fibre-rich feeding reduces physical activity. This results in lower heat production caused by activity, compensating for the increased fermentation heat (Rijnen, 2003); as a result, the measured RE value does not correspond to the NE value of fibre. Such effects should be considered when calculating NE, since this otherwise leads to an undesirable mixing of requirement determination and feed evaluation.

5. There is a **methodological constrain with experimental determination of the NE value**. To determine the RE of a feed, respiratory measurements have to be carried out in studies where the feed is added to a basal diet. Because this is generally not done due to the high effort involved, an assumption is necessary for the level of basal metabolism¹⁰; this value is added to the measured RE value. This assumed value is not the same for the different NE systems and the actual basal metabolism can also be influenced by experimental conditions, especially the length of food withdrawal. This problem is therefore a crucial, fundamental criticism of NE systems. It also means that NE values differ between different NE systems; this poses major difficulties for conversion between NE systems. If new information on maintenance or basal metabolism becomes available, it could not be implemented into recommendations for supply of energy but would lead to modified NE values for feeds and hence to a revision of the feed tables.

6. **Experimental verification of NE values** is theoretically possible but unrealistic: on the one hand, because the value defined in each system for maintenance or basal metabolism has to be adopted, and represents therefore not a measured value; on the other hand, because only a few institutions currently have respiration chambers for large animals. Digestibility studies, which are sufficient for ME determination and can be complemented by urine collection, can be regarded as acceptable for the purposes of feed evaluation, whereas the total metabolism studies required for NE determination are not really feasible.

¹⁰ Basal metabolism is defined as heat production without food intake, and therefore corresponds to the body nutrients mobilised in response to hunger (negative RE). For this reason, no maintenance requirement for NE can be defined since the maintenance requirement corresponds to the ME supply required to prevent mobilisation of body nutrients. Maintenance requirement is therefore greater than basal metabolism.

5. Current net energy systems

An assessment of energy evaluation of feed according to NE must consider the differences between NE systems, in addition to the general aspects outlined above. Three current NE systems¹¹ based on RE during growth implemented the following formulas:

Rostock system (Beyer et al., 2003)

$$\text{NE} = 11.0 \text{ DXP} + 34.0 \text{ DXL} + 12.7 \text{ ST} + 11.6 \text{ SU} + 12.0 \text{ DOR}$$

INRA (2004)

$$\text{NE} = 12.1 \text{ DXP} + 35.0 \text{ DXL} + 14.3 \text{ ST} + 11.9 \text{ SU} + 8.6 \text{ DOR}$$

CVB (2016)¹²

$$\text{NE} = 11.70 \text{ DXP} + 35.74 \text{ DXL} + 14.14 \text{ ST} + 12.73 \text{ pd SU} + 9.74 \cdot \text{fermented carbohydrates}^{13}$$

Key aspects of these equations are addressed below. The factor for DXP differs between the NE systems only to a small extent. This is the case also for DXL and for SU. The value given for DOR in the Rostock system applies to rations with an energy digestibility higher than 80 %; however, if the energy digestibility is only 60 or 65 % for example, the factor is 9.2 or 9.9 and is therefore close to the other systems. This also shows that the energy contributed by this fraction tends to be underestimated at least for normal energy-rich rations according to INRA (2004) and CVB (2016). Due to the high ST content of many feeds, however, the differences in the factor for ST are more important. Based on respiration studies measuring the effect of added pure starch on energy retention, NE values above 14 kJ per gram of starch are to be regarded as unrealistically high. Rather, the energy utilisation of starch is consistently in the range of 75 to 76%¹⁴. The common statement that protein is under-valued in the NE system according to INRA is therefore not correct. Rather, there is a substantial over-valuation of starch, which is associated with a relative decrease in the value of the other nutrients. Because the selection of individual components in compound feed formulation focuses not on the absolute energy values of the nutrients but on their relative values, starch-rich components are over-evaluated, especially compared to protein- and fibre-rich components.

6. Summarising facts

6.1. NE systems

The advantages and limitations of feed evaluation based on NE can be summarised as follows:

1. With NE systems, energy retention is more accurately predicted in rations with high protein contents (i.e. exceeding minimum requirements) and in fat-rich feeds.
2. The energy value of starch is over-estimated by the NE according to INRA (2004) and CVB (2016).

¹¹ The 'Potential Physiological Energy' in the Danish system (Tybirk et al., 2006; Boisen, 2007) is derived from the ATP-producing capacity of the nutrients. The intention of this system agrees with that of ME as the energy supply capacity of the feed. The energy values of the respective nutrients are close to NE values but not identical to them, which is the reason why they are not listed here for comparison.

¹² Formula V.F10; (Formula V.F09 also includes volatile substances and glycerol.)

¹³ Total of digestible NSP, fermented SU and fermented ST

¹⁴ Virtually identical values have been found in rats (75.5; Nehring et al., 1961) and in humans (75.8; Jentsch et al., 2000b).

3. The requirements for maintenance, gestation, milk production, physical activity and thermoregulation must be converted into NE growth, which makes the system harder to understand and difficult to communicate.
4. The different NE systems provide different values for the same feed and are not compatible.
5. Experimental verification of a feed value is to be regarded as unrealistic due to the high effort involved.
6. If new findings on energy metabolism are taken into account in NE systems, the feed tables will have to be changed. This especially concerns the energy value of protein, which is to be regarded as variable, and the basal and maintenance requirements.

6.2. ME system

The advantages and limitations of feed evaluation based on ME can be summarised as follows:

1. The ME describes the energy provided for the metabolism. A slight limitation is due to the fact that the energy losses via urine also depend on the protein quality and the animal's protein deposition. Only a system based on digestible energy (DE) would be unaffected, as would every NE system. The ME therefore does not include differences in the energy utilisation of nutrients. The ME value of protein applies to rations which allow high protein utilisation; this is appropriate because it is desirable in practice to calculate the protein content of the ration based on the requirements. The lower energy utilisation of ME from fermented carbohydrates compared with carbohydrates digested in the small intestine is based mainly on fermentation heat, according to current knowledge (Susenbeth, 2005). This heat production is included in the factor for DOR because it is both a characteristic which is clearly attributable to the feed, and constant. All energy losses associated with fermentation can therefore be recorded with sufficient accuracy using a digestibility study.
2. The higher energy utilisation of energy from fat is not taken into account at ME level. In the view of the AfBN, this is the only unsolved problem in the energy evaluation of feeds - but not for the purposes of performance prediction.
3. The ME is basically valid for maintenance requirements and all types of performance. In addition, it has the highest compatibility with all other systems since the various NE values are generally derived from the ME or the digestible nutrients.
4. Recent results of digestibility studies conducted in various countries can be adopted independently of the energy evaluation system and used to extend the feed tables. Conversely, published NE values can only be used within the respective system. The methodological details of digestibility studies are harmonized internationally (GfE, 2005).
5. New findings on requirements can be introduced into practice much more easily in the ME system, since they only concern the recommendations for energy supply and do not require corrections to the feed tables.

6.3. Aspects relating to compound feed formulation and feeding practice

Evaluation at ME level is not just one system among others but the common basis of all energy evaluation systems¹⁵. A ME derived from the content of digestible nutrients for a given feed also allows the calculation of the NE value in the respective systems. The ME therefore ensures compatibility between NE systems.

If experimental verification of a feed value is needed, this can be done on the basis of digestibility studies with additional recording of urinary losses. As a result, the ME value is based on a

¹⁵ Because ME differs from DE only by including energy losses via methane and urine, this is also true for DE.

measurement and is not determined by calculation. Conversely, the NE value of a feed material or feed mixture cannot be tested experimentally with reasonable effort.

Performance prediction has a key role in ration formulation¹⁶ but must not be limited to energy retention. For this purpose, the levels of all relevant ration constituents, the protein quality and the animals' properties must also be known. Combined with this information, energy evaluation of feed at ME level allows a precise and comprehensive performance prediction.

It has been postulated that feed formulation based on NE would lead to lower protein concentrations in compound feed and to a reduction in price since, in contrast to ME, NE classifies low-protein and starch-rich feeds as more beneficial in energy terms and therefore downgrades protein-rich feeds. This is of crucial importance because it has also been postulated that conversion from ME to NE would contribute to a reduction in N emissions. These postulates were extensively tested using practical conditions by a large compound feed manufacturer in cooperation with the AfBN. These tests showed that feed formulation based on ME (GfE, 2008) leads to the same feed material inclusion and thus to identical crude protein concentrations and prices as formulation based on NE (INRA, 2004). In both systems, the minimum price was achieved at the minimum crude protein concentration if amino acid levels were used on the basis of precaecal digestibility. This means that the goal of reducing N emissions is equally achievable in both systems¹⁷.

The NE supply recommendations for different growth stages, sexes and genotypes are not currently available. In addition to maintenance and growth requirements, the growing pig's needs for physical activity and thermoregulation must be taken into account. For example, there are differences in physical activity between castrated males and boars, and activity is also influenced by housing conditions. However, such requirements can be stated in a physiologically meaningful way only at ME level.

There is therefore no reason, either from a scientific perspective or from the perspective of pig feeding practice, to convert from ME to one of the existing NE systems. According to current knowledge, ration formulation based on ME is therefore to be regarded as best practice.

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¹⁶ In compound feed manufacturing, optimising rations generally means minimising prices while maintaining predetermined concentrations of nutrients. Not before the effects of varying concentrations on all relevant fattening traits (growth, carcass yield, feed intake, nutrient excretion) are considered and thus a prediction of performance is conducted, the term "optimisation" can be justified.

¹⁷ For correct comparison of the two systems, it was necessary to carry out the formulations on the basis of the levels of precaecally digestible amino acids and to specify the precisely corresponding NE and ME values as target values of the mixture. Failure to observe these requirements might be the reason why divergent results of such comparisons have been reported on various occasions. However, it is not the task of the energy evaluation system to determine the optimum crude protein concentration of compound feeds. Concentrations of protein and amino acids must be ascertained by target setting derived from the requirements.

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