Shortcomings of the Energy Evaluation Systems in Pigs: a Review

Csaba SZABÓ (✉)
Veronika HALAS

Summary

The aim of that review is to present the principles of energy evaluation systems used in pig feeding and to stress out some key consideration when introducing Net Energy (NE) systems and some areas of future research. Based on the relevant literature data it can be stated that despite the mentioned shortcomings of the currently used energy systems, we have to admit that NE and/or Potential Physiological Energy (PPE) are the least inaccurate feed evaluation, therefore they are recommended to use in practical pig production. There is not enough evidence to favor any of these systems. According to our opinion some kind of harmonization would be beneficial, since the European feed market would need a common understanding of energy (feeding) value of compound feeds and feedstuffs. However, according to our view it could be achieved only by the lobby and cooperative action of the European feed manufacturers.

Key words

pig nutrition, energy systems, feed evaluation

Kaposvár University, Guba Sándor 40, 7400 Kaposvár, Hungary
✉ e-mail: szabo.csaba@ke.hu

Received: June 14, 2013 | Accepted: July 4, 2013

Aim

The biological processes in the body require energy provided by the feed. It has been demonstrated that for the maximum protein deposition feed must contain energy in a certain ratio relative to protein (amino acids) (Batterham, 1994). Therefore, the proper energy evaluation of the feedstuffs and acquaintance of the animal's requirement is crucial to maximize profitability. Even within Europe, different systems are preferred in different countries (Wenk, 2004). The most probable reasons behind that is the considerable high difference between the set of commonly used feedstuffs among countries and the and the characteristics of the pig sector in terms of genetic lines used, and goals of production.

In countries where pig fattening is based mainly on cereals and soybean meal the DE and ME systems work quite well. While in countries having significant sea commerce and therefore using many unconventional feedstuffs with variable fiber content and intensive and large scale pig farming NE systems are preferred. However this "status quo" is going to be changed by the globalization and the increasing volume of by-products from ethanol production in Europe. These changes force us to use more byproducts in our pig diets and consequently move to the net energy evaluation systems. Therefore, the aim of that review is to present some key consideration when introducing NE systems and some areas of future research.

Brief overview of energy evaluation systems used in swine feeding

In classical animal nutrition the energy value of feedstuffs and compound feeds could be described by digestible, metabolizable or net energy content (DE, ME and NE, respectively, Figure 1). The nutritive value of the feeds is principally determined by the digestibility of nutrients. About 10 to 30 percent of dietary gross energy is lost via faces. This large variation is mainly caused by the quite variable content and digestibility of dietary fiber, fat and protein of feedstuffs. The metabolizable energy is defined by the energy content of feed that is not excreted via feces, urine and gases. Urinary energy is mainly attributed to the non-utilized proteins, while gas energy shows a strong correlation with fermentable fiber content of the feed. There is not much advantage to use the ME over DE in mixed feeds for swine, since in most of the cases the ME:DE ratio equals to about 0.96 and this value is quite constant (Noblet, 2005). That means that only about four percent of DE is lost as urine and gases (methane and hydrogen). However this average ratio can not be applied to individual feedstuffs (Shi and Noblet, 1993) since they have quite variable dietary fiber (fermentable fiber) and protein content. The energy yielding potential of the feed can be more precisely characterised by its net energy (NE) value rather than by ME or even DE. The term net energy suggests that it can be entirely used by the animal. In classical energetics the net energy is used for maintenance and for animal products, however, it has to be noted that energy requirement for maintenance is in form of heat and it is a non-productive part of NE. The heat increment – which is the difference between the ME and NE – is the sum of the ATP used in metabolism, energy used in absorption and excretion processes, as well as fermentation heat. Subsequently if the nutrient digestibility is high and the nutrient content, particularly the amino acid pattern of the protein complies the requirement of the pigs, than the conversion of the nutrients is high and thus the efficiency of ME utilization to NE is favorable. Contrary, by increasing the fermentable carbohydrate content in the diet the utilization of ME reduces due to the higher methane production and fermentation heat lost. Therefore net energy more accurately predicts the amount of energy used and retained in the pig for fibrous feedstuffs when compared to the ME system (Payne and Zijlstra, 2007).

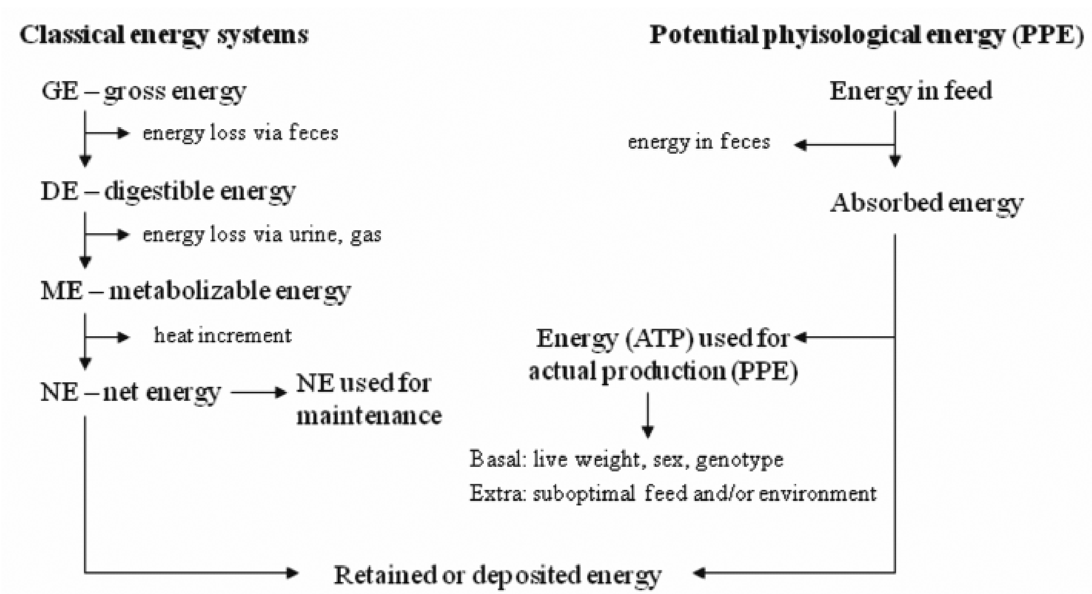

Figure 1. Simple description of the principles of the classical and the physiological energy systems (based on Boisen and Verstegen, 2000)

However, Boisen (2007) argue that NE systems are not suitable basis for feed evaluation because they are developed under specific experimental conditions. Therefore such a system would be not accurate in practical conditions. In response to that they developed the so called Potential Physiological Energy (PPE) system, which estimates the energy yielding potential of feed ingredients based on the oxidation of nutrients used for synthesis of ATP and *in vitro* digestibility methods. The ATP production (thus PPE value) of nutrients has been established by Boisen and Verstegen (2000). The PPE of different nutrients are not influenced by their actual utilization for oxidation or deposition and, therefore, the contributions of the PPE from feed ingredients are additive in diets (Boisen, 2007).

It has to be admitted that the energy partitioning within the body is dynamically influenced by internal (live weight/age, sex, genotype, health status) and external factors (environmental conditions and nutrient supply), therefore such an energy evaluation system that consider the energy yielding potential of the feed by calculating a given value for nutrient conversion cannot be accurately predict the actual production response of the pigs in all practical situation.

Application of NE systems

Major net energy systems for pigs developed in France (INRA), the Netherland (CVB) and in Denmark (potential physiological energy – PPE). The newest recommendation which contains NE recommendation for swine is the 11th Nutrient Requirements of Swine (National Research Council, USA) 2012 edition. However, the net energy values published in this book is based on the prediction equations published by Noblet et al. (1994). Current prediction equations of net energy content in complete diets as summarized by Noblet (2000) are based on the digestible nutrient content (Table 1). These equations were derived from a combination of digestibility and respiration (measurement of heat production) experiments with diets that typically cover a greater range of nutrient concentrations than commonly found in commercial swine diets (Moehn et al., 2005). Nutrients considered in the equations are digestible crude protein (dCP), digestible ether extracts (dEE) and digestible carbohydrates. The different equations developed in various countries having similar coefficients for digestible protein and digestible lipid, the main difference is in the consideration of the carbohydrate fraction. Further difference is that the Dutch system (Noblet, 2000) utilizes different analytical methods (enzymatic) for starch and lipid determination.

However, it has to be stressed out that prediction equations developed for complete diets can not be applied to individual feedstuffs, since nutrient content of them many times falling well out the usual range in complete diets. Therefore, separate prediction equations had been developed (Table 2).

It is obvious that the hierarchy between feeds obtained in the DE or ME systems will vary in the NE system according to the specific chemical composition (Noblet, 2005). The energy value of protein or fibrous feeds is overestimated, while fat or starch sources are underestimated when expressed on a DE (or ME) basis. These conclusions are more clearly demonstrated in Table 3 for a series of ingredients. High fat or high starch ingredients has considerable lower DE and ME value while protein rich and/or fiber rich ingredients have higher DE and ME values compared their ranks in NE system. For mixed ingredients, the negative effect of protein or fiber (i.e., protein sources) on efficiency of DE or ME for NE is partly counterbalanced by

Table 1. Coefficients used in equations to calculate net energy (MJ/kg dry matter) in mixed feed (Noblet, 2000)

NE system	Equation
French	0.0113 dCP + 0.0350 dEE + 0.01444 starch + 0.0121 dRes
Dutch	0.0108 dCP + 0.0361 dEE + 0.0135 starch + 0.1027 sugar + 0.0125 dRes

dCP = digestible crude protein; dEE = digestible ether extract; dRes = digestible residue (obtained as difference between digestible organic matter and other digestible nutrients considered in the equation). Composition is expressed as g/kg of dry matter)

Table 2. Some example equation to calculate net energy (MJ/kg) in feedstuffs

Source	Equation (parameters in g/kg)
Noblet et al, 1994	0.0121 dCP + 0.0350 dEE + 0.0143 starch + 0.0119 sugar + 0.0086 dRes
Blok, 2006	0.0117 dCP + 0.0358 dEE (acid) + 0.0142 ST (Am-e) + 0.0128 SU (e) + 0.0098 FCH
Noblet et al, 1994	0.70 DE + 0.0067 EE + 0.0020 starch – 0.0038 CP – 0.0033 ADF

dCP = digestible crude protein; dEE = digestible ether extract; (acid) = dEE using acid hydrolysis; ST (Am-e) = enzymatic digestible fraction of the Starch fraction, analyzed according to the amyloglucosidase method; dRes = digestible OM – digestible CP – digestible ether extract – starch – sugar; SU (e) = enzymatic degradable fraction of total sugar fraction; FCH = fermentable carbohydrate fraction

Table 3. Relative energy values of feedstuffs in DE, ME and NE systems (based on Noblet et al., 1993)

Energy system	DE	ME	NE
Diet*	100	100	100
Wheat	97	97	100
Corn	95	94	102
Tapioca	95	96	106
Soybean meal	98	94	66
Peas	97	97	91
Animal fat	179	182	242

* Diet corresponds to a 3.5% animal fat, 15% soybean meal and 81.5% wheat diet.

the positive effect of starch or fat (i.e., energy sources). It is also demonstrated that diets formulated on NE concept and having lower protein but the same amino acid content resulted in even higher energy retention that leads to a lower surplus of dietary N and thus a lower N excretion (Noblet and van Milgen, 2004).

Considerations on Net Energy systems

The aim of pig production is to provide the sufficient, but not more nutrient to reach the optimum performance of the animals, to achieve profitable production. To achieve this we need accurate units to express the nutritional needs of the animals and the nutritive values of the feedstuffs. Therefore, before introducing a new system in a given pig production industry, this system should be checked for its accuracy and limitations. The North-American swine producers were long relying on the DE and ME system, which provided sufficient accuracy on the corn – soybean meal based diets (Pettigrew et al., 2009). However, by the boom of the bio-ethanol industry the fiber-rich co-products appeared in significant amount on the market, and therefore the previous energy system needed to be reconsidered. To check the benefit of introducing a net energy system, several large scale studies were conducted (Alle et al., 2009). The results of Kil et al. (2009) showed that the measured values for NE of diets were lower ($P<0.05$) than the values predicted from INRA and CVB. This was true for growing pigs as well as for finishing pigs, but values for finishing pigs obtained in that experiment were closer to the values predicted from INRA and CVB than the values for growing pigs. Values obtained for the diets used in the trial were also closer to values predicted by PPE than the values predicted by INRA and CVB. For ingredients, the measured NE values were lower ($P < 0.05$) than the predicted values for growing pigs, regardless of which system they were compared with. However, the measured values for finishing pigs were relatively close to the predicted values from the three European systems. However, the ranking of the six ingredients was similar if based on measured and predicted values. Pettigrew (2008) reported summarized result of several trials (Table 4).

The measured NE values for diets are all substantially lower than values predicted by the European systems. However, Van Oeckel et al. (2005) demonstrated that some tested feed ingredients like wheat bran and sunflower meal samples had six and eleven percent higher actual net energy values compared to the CVB (2004) tabular values, respectively.

These data also show, in agreement with Noblet (2007), that it is extremely important to use the same energy system for expressing the diet energy values and the pig's energy requirements. It is important to note that predicted NE values (prediction equations) should be carefully evaluated, since equations were often developed using complete diets, and caution is needed when extrapolating to individual ingredients (NRC, 2012).

Energy values assigned to ingredients and energy requirements are affected by the chemical-physical properties of the ingredient and the physiological state of the pig (growth, gestation, lactation) (NRC, 2012). One criticism of the NE systems is that the values are determined in standardized conditions and therefore application in practical conditions could result inconsistent production response (Boisen and Verstegen, 1998). That was one of the reason to that the PPE system has been developed. The PPE system is based on the potential production of ATP when the different nutrients are oxidized at cellular level (Boisen, 2007). The feed value is based on solely on the properties of the feed itself, and relevant information (*in vitro* digestibility) of the actual feed samples. In practical feed formulation often average energy values from feed composition tables are used, because the actual energy value determination would need animal experiment and quite a bit of time. The PPE system provides the opportunity of the energy evaluation of each feed sample. However, there are many factors affecting the utilization of DE (and ME) as net energy. We should not forget that our final aim is the production of animal product, therefore leaving out the testing of production response, might lead to incorrect conclusions. Even, Boisen and Tybirk (2007) admit that the PPE system can be further improved by the knowledge of specific effects of

Table 4. Measured and predicted NE values of different growing pig diets (MJ/kg), (based on Pettigrew, 2008)

Experiment	Diet	Measured	INRA-calc	CVB	PPE	ME (NRC)
Corn	Low-fat basal	8.5	10.6	10.8	9.2	15.0
	Low-fat corn	8.5	10.7	11.4	9.7	15.2
	High-fat basal	9.2	12.2	12.3	10.1	16.5
	High-fat corn	8.9	11.9	12.0	10.4	16.4
Soybean meal	Basal	9.3	11.0	11.4	10.3	15.5
	Regular	8.6	10.8	11.1	9.7	15.6
	Low-oligosaccharide	9.0	10.7	11.2	9.5	15.6
Fat	Basal	8.9	10.7	10.7	9.4	15.4
	Soy oil. 5%	9.4	12.0	12.8	10.4	16.4
	Soy oil. 10%	10.1	13.1	13.2	11.4	17.4
	Choice white grease	10.6	13.1	13.1	11.5	17.2
Fiber	Basal	9.5	9.8	9.7	6.4	15.8
	Soy hulls	7.0	8.6	8.7	9.2	13.6
	Wheat middlings	7.8	9.4	9.6	8.5	15.3
Amino acids	High-protein	8.4	11.0	11.2	9.6	15.6
	Low-protein	9.0	10.8	11.4	9.4	15.1
Mean of column		8.9	11.0	11.3	9.7	15.7
Ratio to measured			1.24	1.27	1.08	1.76

diet composition on animal health, behavior and activity, which may influence nutrient requirements and production results.

Current NE systems do not distinguish between the different utilization of ME into maintenance and growth (Noblet and van Milgen, 2004) assuming similar efficiencies for maintenance and energy retention. However, the same authors (van Milgen and Noblet, 2003) demonstrated previously that the energy supply for maintenance has priority over the requirement for production and the utilization of ME for maintenance NE is higher than that for production. The efficiency measured in trials were about 74% to 77% for maintenance (Noblet, 2000), 58% to 60% for protein deposition and 77% to 82% for lipid deposition (van Milgen and Noblet, 1999), 40% to 50% for gestation products (Noblet and Etienne, 1987b) and 72% for milk production (Noblet and Etienne, 1987a; Babinszky et al., 1991). The equations predicting ME utilization summarized by Noblet and van Milgen (2004) estimate substantially higher efficiency for growth than for maintenance (Table 5). These values are contradictory with the above mentioned efficiencies. One reason could be that the prediction equation for maintenance was developed on sows, while the one for growth was achieved on growing pigs.

Anyway, the maintenance energy requirement as well as the energetic efficiency of protein deposition decreases with age, therefore the NE content of feeds determined on sows cannot be accurate for growing pigs. Different efficiency values suggest that shift in maintenance energy requirement as well as change in composition of tissue accretion makes quite a bit of difference in the estimated amount of dietary NE available for growth. In case of suboptimal environmental conditions maintenance energy requirement might be even 30% higher than the basic rate (Black et al., 1999).

Despite the above mentioned shortcomings of the currently used energy systems, we have to admit that NE and/or PPE are, to date, more accurate feed evaluation systems than ME or DE based-systems, therefore they are recommended to use in practical pig production.

Future perspectives

Current NE systems provide advantage over the DE or ME system, however, they still presents many elements of inaccuracy. Prediction equations are mainly based on digestible nutrients and even the changes in digestibility over age is hardly taken into account. We also have to improve our understanding of the utilization of ME to NE, and this would have influences in feed evaluation, nutrient requirement and thus in feed formulation upon different feeding regimens and environmental circumstances.

The diversity of energy evaluation systems makes it difficult to compare or cross use of requirement recommendations and feed tables. There were some attempts to develop a unified European energy evaluation system encouraged for instance by European Association of Animal Production but according to our view this is a rather optimistic plan to date. The reason is that countries having strong and long tradition in pork production invested a lot in their systems (providing a business advantage), and therefore hard to believe that any of other countries would give up his position. According to our opinion some kind of harmonization could be achieved trough cooperative action of the European feed manufacturers, since the feed market would need a common understanding of energy (feeding) value of compound feeds and feeding stuffs.

Table 5. Estimated ME utilization (%) for growth (k_g) and maintenance (k_m) of pigs (based on Noblet and van Milgen, 2004)

Feed	Ether extract (%)	Starch (%)	Crude protein (%)	ADF (%)	k_g	k_m
Barley	1.82	52.19	10.08	5.46	74.9	68.2
Corn	3.72	64.11	8.15	2.59	75.2	68.5
Wheat	1.48	60.59	10.54	3.12	75.0	68.3
Wheatbran	3.48	19.77	14.77	11.85	74.4	67.7
Vegetable oil	100	0	0	0	78.3	73.8
Soybean meal	1.84	0	45.32	7.29	73.5	67.3
Diet*	7.12	43.35	13.86	4.60	74.9	68.4

* Diet composition: 20% barley, 20% corn, 30% wheat, 9.7% wheat bran, 5% vegetable oil, 12.4% soybean meal

References

Allee G.L., Pettigrew J.E., Patience J.F., Stein H.H., Kil D.Y., Beaulieu D.B., Hinson R.B. (2009). North American Swine Energy System: Experimental Strategy and Methods. J. Anim. Sci. 87 (E-Suppl. 3):98 (Abstr.)

Babinszky L., Verstegen M.W.A., Hartog L.A., van der Hel W., Zandstra T., Dam J.T.P. (1991). Effect of dietary carbohydrate and fat on energy and nitrogen balances and milk production of lactating sows. In: C. Wenkés M. Boessinger (Eds.) *Energy Metabolism of Farm Animals*, EAAP Publications, ETH- Zürich, Switzerland , 286 - 271.

Batterham E.S. (1994). Protein and energy relationships for growing pigs. In: Principles of growing pig science (D.J.A. Cole, J. Wiseman and M.A. Varley, eds), Nottingham University Press, Sutton Bonington, 107-121.

Black, J.L., Bray H.J., Giles L.R. (1999). The thermal and infectious environment. In: A quantitative biology of the pig, (I Kyriazakis,eds), CABI Publishing, p 71-97.

Blok M.C. (2006). Development of a new net energy formula by CVB, using the database of INRA. In: Int. Sym. Proc. Net energy systems for growing and fattening pigs. Vejle, Denmark, 40-57.

Boisen S. (2007). A New Concept for Practical Feed Evaluation Systems. DJF Animal Science No. 79. Research Centre Foulum, Denmark, 1-70.

Boisen S., Verstegen M.W.A. (1998). Evaluation of feedstuffs and pig diets. Energy or nutrient-based evaluation systems? I. Limitations of present energy evaluation systems. Acta Agriculturae Scandinavica, Sect. A, Animal Science, 48:86-94.

Boisen S., Verstegen M.W.A. (2000). Developments in the measurement of the energy content of feeds and energy utilisation in animals. In: Feed evaluation – principles and practice (P.J. Moughan, M.W.A. Vertegen, M.I. Visser-Reyneveld, eds), Wageningen Press, The Netherlands, p 57-76.

Boisen, S., Tybirk P. (2007). A new practical feed evaluation system for pigs. In: Energy and protein metabolism and nutrition (I Ortigues-Marty, eds), EEAP publication No. 124, Wageningen Academic Publishers, The Netherlands, p. 567-568.

CVB (2004). The Livestock Feed Table. Centraal Veevoederbureau, Lelystad, Netherlands.

Kil D.Y., Ji F., Hinson R.B., Beaulieu A.D., Stewart L.L., Allee G.L., Patience J.F., Pettigrew J.E., Stein H.H. (2009). Comparison of measured values for NE in diets and ingredients fed to pigs and values predicted from European energy systems. J. Anim. Sci. 87 (E-Suppl. 3): 100 (Abstr.)

Noblet J., Etienne M. (1987a). Metabolic utilization of energy and maintenance requirements in lactating sows. J. Anim. Sci. 64: 774-781.

Noblet J., Etienne M. (1987b). Metabolic utilization of energy and maintenance requirements in pregnant sows. Livest. Prod. Sci. 16: 243-257

Noblet J., Fortune H., Dupire C., Dubois S. (1993). Digestible, metabolizable and net energy values of 13 feedstuffs for growing pigs: effect of energy system. Anim. Feed. Sci. Technol. 42:131-149.

Noblet J., Fortune H., Shi X. S., Dubois S. (1994). Prediction of net energy value of feeds for growing pigs. J. Anim. Sci. 72:344-354.

Noblet J. (2000). Digestive and metabolic utilization of feed energy in swine: application to energy evaluation systems. J. Appl. Anim. Res. 17: 113-132.

Noblet J., van Milgen J. (2004). Energy value of pig feeds: effect of pig body weight and energy evaluation system. J. Anim. Sci. 82(E. Suppl.): E229-E238

Noblet J. (2005). Recent advances in energy evaluation of feeds for pigs. In: Recent advances in animal nutrition (P.C. Garnsworthy and J. Wiseman, eds). Nottingham University Press, UK.

Noblet J. (2007). Net energy evaluation of feeds and determination of net energy requirements for pigs. Revista Brasileira de Zootecnika, 36: 277-284.

Moehn S., Atakora J., Ball R.O. (2005). Using net energy for diet formulation: potential for the Canadian pig industry. Advances in Pork Production, 16: 119-129.

National Research Council (2012). Nutrient Reqirements of Swine. Eleventh revised edition. National Academy Press, USA.

Payne R.L., Ziljstra R.T. (2007). A guide to application of net energy in swine feed formulation. Advances in Pork Production 18: 159-165.

Pettigrew E.J. (2008). North American swine energy system. Research report. National Pork Board, Des Moines, USA.

Pettigrew J.E, Allee G.L., Patience J.F., Stein H.H., Kil D.Y., Beaulieu D.B., Hinson R.H. (2009). North American Swine Energy System: Introduction. J. Anim. Sci. 87 (E-Suppl. 3): 97 (Abstr.)

Shi, X.S., J. Noblet 1993. Digestible and metabolizable energy values of ten ingredients in growing pigs fed ad libitum and sows fed at maintenance level, comparative contribution of the hindgut. Anim. Feed Sci. Technol. 42: 223-226.

van Milgen J., Noblet J. (1999). Energy partitioning in growing pigs: the use of a multivariate model as an alternative for the factorial analysis. J. Anim. Sci. 77: 2154–2162.

van Milgen J, Noblet J, Dubois S. (2001). Energetic efficiency of starch, protein and lipid utilization in growing pigs. J Nutr. 131(4):1309-1318.

van Milgen J., Noblet J. (2003). Partitioning of energy intake to heat, protein, and fat in growing pigs. Anim. Sci. 81(E. Suppl. 2): E86–E93.

Van Oeckel M.J. Vanacker J., Warnants N., De Paepe M., De Brabander D. (2005). The impact of different crude fibre sources int he diet of fattening pigs on the nitrogen excretion via faeces and urine: In: Green Pork Production, 25-27 May, Paris, France p. 89-90.

Wenk C. (2004). Energy evaluation systems in Europe. EAAP meeting of Pig Comission, Bled, Slovenia.

acs78_22