Using Net Energy for Diet Formulation: Potential for the Canadian Pig Industry

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Introduction

Feed is the greatest single cost factor in pig production. In pig diets, energy accounts for the largest proportion of the cost. Therefore, it is critically important that the energy content of a diet is characterized in the best possible way. There are several systems available for the characterization of dietary energy. The most common ones - digestible and metabolizable energy - describe the energy a pig can potentially derive from the feed. Net energy has been proposed as a superior system that describes the feed energy a pig actually does use. The following will describe these energy systems and make the case why net energy should be adopted by the Canadian pig industry.

Overview of Energy Systems.

Energy is not a nutrient per se, but a quality associated with the nutrient content of feedstuffs and mixed diets. Carbohydrates - starch, sugar and fiber - serve as substrates for oxidation (the processes that convert carbon from the diet to carbon dioxide, CO_2) to provide energy for metabolic processes. Feed protein and lipids in a diet mostly serve as components of body protein and lipid deposition, but can also be oxidized to provide energy for metabolic processes. The amount of energy that can be derived from dietary nutrients differs between protein, lipids and carbohydrates. Energy evaluation, and the use of the most accurate system to describe this energy, are of central importance in the formulation and assessment of pig diets. Common systems to describe dietary energy are gross energy, digestible energy, metabolizable energy and net energy.

Gross energy (GE), or heat of combustion, is the energy released by burning a sample of feed in excess oxygen. As such, gross energy is meaningless for pig production, because it does not take into account any of the losses of energy during ingestion, digestion and metabolism of feed. In fact, 1 kg of starch has about the same gross energy content as one kg of straw even though the energy in the straw can not be used by the pig. However, gross energy is the first stop in further evaluation of feed energy.

Digestible energy (DE) is the gross energy of feed minus the gross energy of feces. Therefore, this energy system takes into account the digestibility of feed and gives a useful measure of the energy the pig may be able to use. The advantage of digestible energy is that it is easy to determine. The disadvantage is that it does not take into account losses of energy in urine and as combustible gases and during the metabolism of the feed. These losses vary among feedstuffs. DE, therefore is a variable overestimate of the energy available to the pig. DE overestimates the contribution of protein and fiber to dietary energy. This energy system is widely used in North America and in a variety of European countries, predominantly because it is easy to measure DE.

The next system is metabolizable energy (ME), which is defined as the digestible energy minus energy excreted in urine and as combustible gases, e.g. methane. By taking into account these losses, metabolizable energy gives a better estimate of the energy available to the pig for protein and lipid synthesis. ME corrects digestible energy for some of the effects of quality and quantity of protein (urine energy) and fiber (methane). The metabolizable energy system is widely used in Europe and North America.

Net energy (NE) is defined as metabolizable energy minus the heat increment, which is the heat produced (and thus energy used) during digestion of feed, metabolism of nutrients and excretion of waste. The energy left after these losses is the energy actually used for maintenance and for production (growth, gestation, lactation). That means that net energy is the only system that describes the energy that is actually used by the pig. Net energy is, therefore, the most accurate and unbiased way to date of characterizing the energy content of feed. However, NE is much more difficult to determine and more complex than DE or ME, which may be a reason why it is not as widely used as it should be. Currently, only France, The Netherlands and Germany have developed net energy systems to describe dietary net energy contents, although research into net energy has been conducted in several countries.

Current Net Energy Systems

The NE systems currently in use – French (Noblet et al. 2003), the Netherlands (CVB 2003) and the Rostock system (Nehring and Haenlein 1973, Hoffmann et al. 1993), are based on the digestible nutrient content in feedstuffs and mixed diets. These contents are used to predict the net energy content in complete diets using regression equations. 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. This assures that the nutrient concentrations in practical diets falls within the tested concentrations and avoids problems arising from extrapolating to greater or lesser concentrations than tested. Nutrients considered in the equations are digestible crude protein (dCP), digestible crude lipids (dCL) and digestible carbohydrates. The latter is subdivided into fractions: starch, sugar, crude fiber, neutral and acid detergent fiber, organic residue and possibly other fractions. These data were used to derive regression equations presented in **Table 1**.

Table 1. Coefficients used in equations to calculate net energy in mixed feed (Noblet 2000)

System	Digestible protein	Digestible lipid	Digestible carbohydrates
French	0.0113	0.0350	0.0144 * starch + 0.000 *dCF +0.0121 * dRes
Dutch	0.0108	0.0361	0.0135 * starch +0.0127 * sugar +0.0095 * dRes
Rostock	0.0109	0.0361	0.0090 *dCF +0.0125 * dRes

Note: coefficients describe MJ NE/g of nutrient. dCF: digestible crude fiber, dRes: digestible organic residue.

Although there is reasonable agreement among the energy systems regarding the net energy coefficients for digestible protein and lipids, they disagree on the fractionation and coefficients for carbohydrates.

A second method of estimating net energy is from DE or ME content of the complete diet. Noblet (2000) proposed the equations (energy in MJ/kg dry matter, nutrients in g/kg dry matter; CP: crude protein, CL: crude lipids, CF: crude fiber):

NE=0.703*DE-0.0041*CP+0.0066*CL-0.0041*CF+0.0020*starch

NE=0.730*ME-0.0028*CP+0.0055*CL-0.0041*CF+0.0015*starch

A third possibility is to estimate the NE content of individual feedstuffs. Both the Dutch (CVB 2003) and the French (Sauvant et al. 2004) have published extensive feed tables that list the common and 'exotic' feedstuffs for swine, their nutrient composition and estimates of their net energy contents. A drawback of such tables is that they generally only show the mean for a feedstuff, whereas in practice there is a large variability in the nutrient composition (protein, lipid, type and quality of carbohydrate), and hence energy content between batches of the same feedstuff. Noblet et al. (2003) proposed a system to estimate the net energy content of feedstuffs based on chemical analysis. In short, they propose to calculate the gross energy content in feedstuffs based on the nutrient content determined during proximate analysis. Then, the energy digestibility is estimated for major feedstuffs based on the content of key nutrients, mainly the content of types of fiber, which may impair energy digestibility. The estimated DE is then multiplied by a feed-specific factor to estimate the NE content of a particular feedstuff. Finally, the NE content of a complete diet is calculated as the sum of the energy contained in each of its components. This complex calculation uses many estimates and many assumptions.

■ Consequence of Energy System for Feed Evaluation

The main difference between DE or ME and NE is that the former two express *potential* energy, while the latter expresses useable energy, and includes the efficiency with which nutrients can be utilized. This efficiency is different between nutrients. Body protein is subject to a constant breakdown and synthesis process, during which a certain fraction of amino acids is inevitably lost. Protein synthesis requires energy, and the repeated breakdown and synthesis of protein increases this energy expenditure; this means that dietary protein is used with a mean efficiency of only 54% for body protein deposition ('preferred value', ARC 1981). In comparison, starch and lipids are utilized for lipid deposition with a mean efficiency of 74% and 90%, respectively (de Lange and Birkett 2004). During the hindgut digestion of fiber, volatile fatty acids are produced, which are used with a lower efficiency than sugars absorbed after small intestinal digestion, resulting in an efficiency for lipid deposition of only 50%.

The consequences for feed evaluation are illustrated in **Tables 2 and 3**. When the ME content in common feedstuffs is lower than the DE content, the ranking of feedstuffs according to their energy content is similar. However, when switching to NE, the energy content of feedstuffs rich in protein and/or fiber is considerably reduced. For example, soybean meal has a greater DE and ME content than barley, but a considerably lower NE content. Canola meal and sunflower meal, which contain large amounts of protein and fiber, are valued much lower relative to barley under the NE system. Conversely, fats and oils are allocated a much greater value than under the digestible or metabolizable energy system. The different energy evaluation also affects the cost of energy ($/tonne divided by MJ energy) of different feedstuffs (**Table 4**). Again, the cost per MJ increases for protein-rich feedstuffs under the NE system, while the cost/MJ decreases for fat-rich feedstuffs, compared to the DE or ME system.

Table 2. Energy contents (MJ/ kg dry matter) in a variety of feedstuffs (Noblet et al. 1993)

	DE	ME	NE
Barley	15.09	14.76	11.51
Wheat	16.17	15.81	12.14
Peas	16.22	15.67	11.05
Soybean meal	16.35	15.28	8.02
Canola meal	13.03	11.83	6.85
Sunflower meal	9.31	8.28	4.92
Animal fat	29.83	29.59	29.32

Table 3. Energy contents in a variety of feedstuffs, relative to barley (after Noblet et al. 1993)

	DE	ME	NE
Barley	100	100	100
Wheat	107	107	105
Peas	107	106	96
Soybean meal	108	104	70
Canola meal	86	80	60
Sunflower meal	62	56	43
Animal fat	198	200	255

Table 4: Cost[1] per MJ energy[2] in a variety of feedstuffs, relative to barley

	DE	ME	NE
Barley	100	100	100
Wheat	116	116	118
Peas	140	141	156
Soybean meal	358	374	556
Canola meal	347	374	504
Animal fat	379	374	294

[1] Source for feed cost: (April 2004)
http://www.gov.mb.ca/agriculture/financial/farm2004/cac45s03.html#ingredient

[2] Energy content in feedstuffs as reported by Noblet et al. 1993

The consequence for diet formulation is that rations formulated under the NE system will be lower in protein (Rademacher 2001), because the cost/MJ energy prohibits the inclusion of a large amount of soybean or canola meal, and favours the inclusion of free amino acids. At the same time, choosing ingredients with a low cost of energy will reduce the cost of a mixed diet by as much as 2% during the grower and finisher phases (Rademacher 2001). This applies to the condition of equal NE contents for higher and lower protein diets. Because of the greater energy efficiency of the low protein diets, the DE or ME contents of such diets are lower than of diets with greater protein content. Conversely, the better value for fat-rich feedstuffs allows increasing the NE of a diet without cost penalty by greater inclusion rates of such fat-rich feeds. Increased net energy content of diets would be beneficial if the growth rate of pigs is limited by their energy (feed) intake.

For the Canadian pig industry, this has important implications. First, the introduction of the net energy system would lead to lower feed cost, which would enhance our competitiveness on the international market by regaining the feed advantage. The reduction in feed cost would probably be greater for the more complex diets typically fed in the Prairie region than for more simple diets based on corn and soybean meal. Second, the different valuation of feedstuffs under the net energy system would make it more economical to use of some domestic rather than imported feedstuffs. For example, the cost of energy in peas decreases from about 40% to less than 30% of the cost of energy in soybean meal when switching from digestible to net energy. This may apply in a similar manner to other domestic crops with a limited content of high-quality protein.

As shown in Table 2, the NE contents of feedstuffs are lower than the DE or ME contents. This means that the energy requirements of pigs must be adjusted to express requirements and feed characteristics in the same system. A simple means of adjustment is to multiply the requirements for DE or ME by 0.71 or 0.74, respectively (Noblet et al. 1994). A more accurate and better way is to calculate the pigs' energy requirements factorially as the requirement for maintenance plus the energy content in body protein (23.7 kJ/g, ARC 1981) and fat (39.6 kJ/g, ARC 1981). The energy content of the diet would therefore be calculated as daily energy requirement divided by daily feed intake. Full application of NE therefore requires accurate measurement of maintenance energy requirement of Canadian pigs and of on-farm feed intake. There are no published maintenance requirements of maintenance energy requirement in modern Canadian pigs.

This approach gives a better control over energy content of diets and can be used to control carcass fatness in slaughter pigs. The benefits are greater with net energy than with DE or ME, because the latter do not allow for differences in energetic efficiencies between nutrients.

▪ Applicability of the Net Energy Systems

There are two aspects, under which the applicability of net energy systems can be assessed: applicability for Canada, especially the Prairie region, and the scientific value.

The NE systems were developed in Europe, and are based on the contents of digestible nutrients in feedstuffs and diets. Using a mean, tabulated value for the content of digestible nutrients in a feedstuff will obviously cause errors in the diet formulation when the feedstuff available to the feed mill has contents that differ from the tables. However, such an error is equally applicable to the digestible and metabolizable energy systems. Of greater impact is the question whether digestibility data gained in Europe are applicable in the Prairies. The climatic and agronomic conditions under which crops are grown in Canada differ markedly from those in Europe. Energy digestibility of barley, at 73.6% to 81.4% (Beames et al. 1996, Fairbairn et al. 1999) determined in Canada, was quite different from the mean value proposed by Noblet et al. (1993, energy digestibility: 82.1%). However, the NE system provides adjustments for energy content and digestibility based on analyzed nutrients in common feedstuffs (Noblet et al. 2003). This would allow the calculation of NE for a feedstuff of known composition. The extent, to which such adjustments are applicable to feedstuffs grown in the Prairie region, needs to be determined.

The coefficients for digestible nutrients used to predict NE in mixed diets broadly reflect the accepted efficiencies with which nutrients are used for energy deposition (e.g. crude lipids: NE value 35.0, gross energy: 39.0, implies efficiency of 35/39.6=0.88). It is therefore likely that these prediction equations would be applicable in Canadian pig production as well. Because the prediction of energy in mixed diets is the key element in a net energy system, this indicates that net energy systems are applicable for use in Canada in their current form. Adjustments for nutrient contents and digestibility in feed ingredients, as implemented in the French system, could be applied in their current form, but should be re-evaluated to provide data specific to Canadian feedstuffs.

▪ Problems with Energy Systems, and Further Development

Despite the benefits, there are some systematic problems with net energy. First, the determination of NE requires the imposition of standardized conditions (Boisen and Verstegen 1998a), and NE values are therefore, strictly speaking, applicable only to the conditions of determination. This means that the approach used to derive NE equations experimentally deliberately avoided the impact of the pig on dietary NE contents. This impact includes body weight, genotype and level of performance.

The pigs' body weight affects nutrient and energy digestibility. Noblet et al. (2003) estimated that the energy digestibility of wheat-soybean meal diets increased from 82.6% at 38 kg to 85.3% at 90 kg body weight. An even greater discrepancy can be seen between growing pigs and sows: Etienne et al. (1997) estimated that the energy digestibility of a given diet was 80% for a 62 kg pig, but 85% for a 246 kg sow. For otherwise equal conditions, this means that the same diet will have greater NE contents when fed to larger, older pigs. The French NE system only partially addresses this problem by proposing different DE:NE ratios for growing pigs and sows (Noblet et al. 2003).

A further problem is that net energy determinations are conducted with a controlled feed intake, usually a multiple of the pigs' energy maintenance requirement. However, pigs on farm don't always eat to the level used to determine NE, and the pigs' voluntary feed intake – expressed as a multiple of the maintenance requirement – changes during the pigs' growth period and differs between sexes (NRC 1998). Noblet et al. (2003) recently proposed that differing feed intake does not affect energy digestibility in growing pigs or sows, implying that the dietary NE content was not affected, either. However, Boisen and Verstegen (1998a) argue that the NE content of feed will increase when the feeding level increases.

Net energy is used for maintenance and for animal performance. Performance can be protein and fat deposition, growth of conceptus products during gestation or milk production during lactation. The efficiency with which energy is used in intermediary metabolism is dependent on the type of performance. These efficiencies are 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 from feed energy (Noblet and Etienne 1987a). This means that the same diet will have quite different NE contents when fed to a grower pig or a lactating sow, or to a finisher pig or pregnant sow. This situation is also true when comparing fat and lean genotypes of pigs, because fat deposition is more energy efficient than protein deposition.

It should be noted that the above limitations apply equally to the DE and ME system. Obviously, greater digestibility of nutrients will increase DE and ME content of a diet. It is equally clear that differences in energy utilization will affect the gain obtained from a diet with constant DE or ME content. The main difference between DE or ME and NE is that researchers working on the net energy system acknowledge the impact of animal factors on dietary energy content, and seek to devise energy predictions that account for such impact. Being aware of the limitations of the net energy system, some researchers (Boisen and Verstegen 1998b, Whittemore 1999, de Lange and Birkett, 2004) have proposed to drop the concept of energy, and model the effects on performance according to the utilization of dietary nutrients. Although such a model would integrate feed and animal effects to achieve the best characterization of the effect of a diet on performance, no such model is yet available. Considerable experimentation is required to obtain the data needed to fully and successfully implement such a model.

▪ Summary and Conclusions

The net energy system provides a more realistic estimate of dietary energy than either the digestible or metabolizable energy system. NE, therefore, allows a better estimate of the effects of diet on performance. The lower energy value for protein and fiber, and the greater value for starch and fat in the net energy system affect diet formulation. Greater use of cheap feedstuffs and limited use of expensive protein-rich feedstuffs would lead to reduced feed costs and lower protein contents, thus reducing nitrogen excretion and the environmental impact of pig production. The different valuation of feeds will favour domestic crops, like peas, over imported ones, like soybean meal. Together, a switch to the net energy system will improve the economics of both Canadian pig and crop production. Therefore, a shift to NE will help the Prairie Provinces regain our traditional feeding advantage relative to our major competitors.

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