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Comparison of growth and efficiency of dietary energy utilization by growing pigs offered feeding programs based on the metabolizable energy or the net energy system

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Abstract

The net energy (NE) system describes the useful energy available for growth better than the metabolizable energy (ME) system. The use of NE in diet formulation should maintain growth performance and carcass parameters when diets contain a diversity of ingredients. This study compared the growth performance of pigs on diets formulated using either the ME or NE system. A total of 944 gilts and 1,110 castrates (initial BW = 40.8 ± 2.0 kg) were allotted to group pens and assigned to one of 5 different feeding programs according to a randomized complete block design. A simple corn-soybean meal control (CTL) established baseline levels of ME or NE concentrations for the other dietary treatments. Thus, for two of the treatments, corn DDGS were added at 25% and formulated to achieve a constant ME or constant NE relative to the CTL (ME-D and NE-D). For the other two treatments, corn DDGS and corn germ meal were added at 15% and 20%, respectively, formulated to achieve a constant ME or a constant NE diet (ME-DC and NE-DC). When required, fat was added as an energy source. Pigs were harvested at an average BW of 130.3 ± 4.0 kg. Growth performance was not affected by treatment (P = 0.581, P = 0. 177 and P = 0.187 for ADG, ADFI and G: F ratio respectively). However, carcass growth decreased with the addition of co-products except for the NE-D treatment (P=0.016, P = 0.001, P = 0.018, P = 0.010 and P = 0.010 for dressing percentage, HCW, carcass ADG, back fat and loin depth respectively). Carcass G:F and lean percentage did not differ among treatments (P = 0.109 and P = 0.433). On the other hand, NE intake decreased (P = 0.035) similarly to that of carcass gain, suggesting a relationship between NE intake and energy retention. Calculations of NE per kg of BW gain differed among treatments (P = 0.010), but NE per kg of carcass was similar among treatments (P = 0.640) This suggests that NE may be better than ME at explaining the carcass results. Finally, ME intake and ME per kg of BW gain were not different among treatments (P = 0.112), but ME per kg of carcass gain was different among treatments (P = 0.048). In conclusion, the sequential addition of co-products in diets formulated on an NE or ME basis can result in similar growth performance, but carcass parameters may be affected independently of the energy system used. However, formulating diets based on NE tended to improve predictability of growth, especially carcass parameters.

Keywords

growth performance, energy efficiency, corn DDGS, corn germ meal, swine

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Comparison of growth and efficiency of dietary energy use by growing pigs offered feeding programs based on the ME or the NE system

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ABSTRACT

The net energy (NE) system describes the useful energy available for growth better than the metabolizable energy (ME) system. The use of NE in diet formulation should maintain growth performance and carcass parameters when diets contain a diversity of ingredients. This study compared the growth performance of pigs on diets formulated using either the ME or NE system. A total of 944 gilts and 1,110 castrates (initial BW = 40.8 ± 2.0 kg) were allotted to group pens and assigned to one of 5 different feeding programs according to a randomized complete block design. A simple corn-soybean meal control (CTL) established baseline levels of ME or NE concentrations for the other dietary treatments. Thus, for two of the treatments, corn DDGS were added at 25% and formulated to achieve a constant ME or constant NE relative to the CTL (ME-D and NE-D). For the other two treatments, corn DDGS and corn germ meal were added at 15% and 20%, respectively, formulated to achieve a constant ME or a constant NE diet (ME-DC and NE-DC). When required, fat was added as an energy source. Pigs were harvested at an average BW of 130.3 ± 4.0 kg. Growth performance was not affected by treatment (*P* = 0.581, *P* = 0. 177 and *P* = 0.187 for ADG, ADFI and G: F ratio respectively). However, carcass growth decreased with the addition of co-products except for the NE-D treatment (*P*=0.016, *P* = 0.001, *P* = 0.018, *P* = 0.010 and *P* = 0.010 for dressing percentage, HCW, carcass ADG, back fat and loin depth respectively). Carcass G:F and lean percentage did not differ among treatments (*P* = 0.109 and *P* = 0.433). On the other hand, NE intake decreased (*P* = 0.035) similarly to that of carcass gain, suggesting a relationship between NE intake and energy retention. Calculations of NE per kg of BW gain differed among treatments (*P* = 0.010), but NE per kg of carcass was similar among treatments (*P* = 0.640) This suggests that NE may be better than ME at explaining the carcass results. Finally, ME intake and ME per kg of BW gain were not different among treatments (*P* = 0.112), but ME per kg of carcass gain was different among treatments (*P* =

0.048). In conclusion, the sequential addition of co-products in diets formulated on an NE or ME basis can result in similar growth performance, but carcass parameters may be affected independently of the energy system used. However, formulating diets based on NE tended to improve predictability of growth, especially carcass parameters.
Keywords: growth performance, energy efficiency, corn DDGS, corn germ meal, swine.

INTRODUCTION

Feed is the largest single expense in pork production, with energy representing the greatest proportion of the total (Noblet, 1994; Stein and Shurson, 2009; Gutierrez and Patience, 2012). Energy systems quantify the concentration of energy in the diet and should account for the energy available to the pig. The purposes of energy systems are to 1) facilitate the blending of diverse ingredients into a diet formulation that results in predictable performance, and 2) serve as a basis for assigning relative economic values to ingredients that vary in energy content. Currently in the U.S., the ME system is widely used, but the NE system is attracting more interest because of its theoretical advantage in quantifying energy supplied to, and utilized by, the pig (Patience, 2012).

The NE system essentially discounts ME estimates by accounting for the metabolic cost of converting ME into useful forms of energy for maintenance and productive functions (NRC, 2012; Patience, 2012). These discounts are variable (89.1, 82.0, 55.9 and 59.2% for fat, starch, fiber and protein, respectively) among dietary components (Noblet, 2005; van Milgen et al, 2008). Thus, useful energy can be overestimated or underestimated by the ME system (Noblet, 1994).

The inclusion of so-called "alternative" ingredients has become common practice in the U.S. swine industry as a strategy to lower the cost of production. These ingredients generally bring increased amounts of fiber into the diet (Gutierrez et al., 2013), or displacement of soybean meal, thereby raising doubt about the effectiveness of the ME system to accurately predict efficiency of diet use (Boyd et al., 2010).

The objectives of this study were 1) to determine if animal growth performance and carcass characteristics are better reflected by ME or NE estimates across diets of diverse composition, and 2) to determine if dietary ME or NE better predict the efficiency of dietary energy utilization across diets differing in ingredient composition.

MATERIALS AND METHODS

The protocol for this experiment was approved by the Institutional Animal Care and Use Committee at Iowa State University (No. 6-12-7396-S).

Animals, Housing and Experimental Design

This experiment was conducted at The Hanor Company Research Facility, (White Hall, IL) in two barns equipped with a computerized feed delivery system (Big Dutchman, Inc., Holland, MI). A total of 2,054 crossbred pigs (1,110 barrows and 944 gilts), the progeny of PIC Camborough sows x TR4 sires (PIC, Hendersonville, TN) and with an initial BW of 40.8±2.0 kg) were assigned on the basis of BW and sex to 19 blocks (10 blocks for barrows and 9 blocks for gilts). They were randomly assigned to 1 of 5 dietary treatments across 95 pens (19 to 24 pigs/pen). Each pen had a completely slatted concrete floor and was equipped with a 4-space stainless steel dry feeder and two nipple drinkers providing *ad libitum* access to feed and water. At the end of the experiment, pigs were shipped in 4 groups (on d 89, 90, 95 and 97 for group 1 to 4, respectively) to Triumph Foods (St Joseph, MO), where carcass data were collected. Within each group, a similar number of the heaviest pigs were harvested each day from each pen to ensure consistent measurements for each treatment (28, 30, 34 and 8% of the total pigs were harvested in groups 1 through 4, respectively).

Dietary Treatments

Diets were delivered to the pigs as a mash in 3 phases: (41-61, 61-83 and 83-130 kg BW for phase 1 to 3, respectively). Barrows and gilts received the same diets, but switched dietary phases at different times, based on BW and previously determined lys requirements for pigs in this herd (PIC, 2011). The 5 dietary treatments (Tables 1 to 3) included a simple corn-soybean meal control diet (CTL) that established the ME and NE concentrations for the other dietary treatments. The next two treatments included corn DDGS (>10% oil; 25% inclusion in phase 1 and 30% in phases 2 and 3) and were formulated either to an equal ME (ME-D) or to an equal NE (NE-D) concentration compared with the CTL. The second set of dietary treatments contained both corn DDGS (15% inclusion for phase 1 and 20% for phase 2 and 3) and corn germ meal (20% for all dietary phases) and were also formulated to either constant ME (ME-DC) or NE (NE-DC) content relative to the CTL. Choice white grease was added to the diets as required; therefore, test diets were isocaloric to the CTL on an ME or NE basis. All experimental diets were formulated to meet or exceed the nutrient requirements for pigs from 40 to 130 kg (NRC, 2012). Standardized ileal digestibility (SID) of lys, minimum ratios of essential amino acids to lys and available P were kept constant across all experimental diets within each phase. Iron oxide was added as a color marker in order to visually distinguish ME-based or NE-based diets.

Chemical Analysis and Calculations

Prior to formulating the diets, samples of corn, soybean meal, corn DDGS and corn germ meal were finely ground and assayed for DM (Method 930.15; AOAC, 2007), ash (Method 942.05, AOAC, 2005), acid and neutral detergent fibers (Van Soest and Robertson, 1979), crude protein as N × 6.25 (Method 984.13 A-D, AOAC, 2006) and ether extract (Method 920.39, AOAC, 2005) at the Agricultural Experiment Station Chemical Laboratories (University of Missouri-Columbia, MO) and for starch (Modified method 996.11, AOAC 1996) at the Monogastric Nutrition Laboratory (Iowa State University, Ames, IA). Values provided from these assays as well as the ME values published in the NRC (2012) were used to estimate NE according to equation [1-7] published in NRC (2012):

$$NE = (0.726 \times ME) + (1.33 \times EE) + (0.39 \times Starch) - (0.62 \times CP) - (0.83 \times ADF)$$

where energy is expressed in kcal/kg and dietary constituents in g/kg.

Growth performance parameters were calculated by measuring BW and feed disappearance, computed on a pen basis and divided by pig days (sum of number of pigs alive within each pen per day) in order to calculate ADG and ADFI, while G:F ratio was calculated by dividing total pig growth by total feed intake.

Dressing percentage was calculated as the HCW divided by the market live BW determined at the research barn times 100. Loin depth and back fat thickness were measured using an optical probe (FOM, FK Technology Fat-O-Meter, Herley, Denmark), with measurements taken between the 3-4th last rib. Percent lean was calculated using the packing plant's own proprietary equation, which involved FOM loin and fat depth. Carcass gain was calculated by subtracting HCW from the initial carcass weight, which was estimated as the initial BW × 0.74. The dressing percentage at the start of the experiment (74%) was assumed to be similar to the final dressing percentage, which, based on the literature, should be approximately correct (Oresanya et al., 2008). Carcass ADG of lean tissue was calculated as the result of multiplying carcass ADG times the lean percentage.

Calculation of ME and NE intake (Mcal /d) was the result of multiplying the ME and NE dietary concentrations times the ADFI (both on an as-fed basis). Concentrations of ME or NE during the entire study were calculated as a weighted average of ME or NE concentrations of phases 1-3. Dietary energy efficiency was determined as ME or NE consumed per kg of BW gain, and was calculated by dividing ME intake or NE intake by ADG. Carcass-basis energy efficiency was determined as ME or NE/kg of carcass gain and was calculated by dividing ME or NE intake by carcass ADG.

The estimated ME and NE available for growth were calculated using the following equations:

$$\text{ME for growth} = \text{ME}_{\text{I}} - \text{ME}_{\text{m}}$$

$$\text{NE for growth} = \text{NE}_{\text{I}} - \text{NE}_{\text{m}}$$

where ME_{I} and NE_{I} are ME and NE intakes in Mcal/d, respectively, and ME_{m} and NE_{m} were calculated using NRC (2012) and van Milgen et al. (2008) equations respectively:

$$\text{ME}_{\text{m}} = 0.197 \times (\text{BW, kg})^{0.60}$$

$$\text{NE}_{\text{m}} \text{ (kJ/d)} = (\text{FHP} \times 0.708 + 207) \times (\text{BW, kg})^{0.60}$$

where NE_{m} was converted to calories using 0.239 as a conversion factor; FHP is the calculated fasting heat production accounting for the level of feed intake using the following equation (van Milgen et al., 2008):

$$\text{FHP (kJ kg BW}^{-0.60} \cdot \text{d}^{-1}) = 436 + 175 \times (\text{NE intake, MJ/d}) / (\text{BW, kg})^{0.60}$$

Median BW was determined to calculate overall ME_{m}, NE_{m} and FHP using the following equation:

$$\text{Median BW, kg} = [\text{Initial BW, kg}] + [(\text{overall ADG, kg}) \times 47]$$

where 47 was the median days on trial.

Statistical Analysis

The UNIVARIATE procedure of SAS (SAS Inst., Inc., Cary, NC) was used to analyze the data for outliers, but no outliers were identified. The MIXED procedure of SAS was applied, including treatment and sex as fixed effects and block as a random effect in the model. Interactions between sex and treatment were tested and eliminated from the model when they were not different ($P \geq 0.10$). Differences among treatments were considered statistically significant with $P \leq 0.05$ and trends with $0.05 < P \leq 0.10$. Least square mean differences among treatments were determined using the protected LSD test. Pen was the experimental unit in all instances.

RESULTS

Chemical Analysis, NE and ME from Ingredients

Dry matter, CP, EE, starch, ADF and NDF, as well as the calculated NE values for the four main ingredients (Table 4; corn, soybean meal, corn DDGS and corn germ meal) were in close agreement with the values published by the NRC (2012). The calculated values for the NE content of each ingredient, based on actual chemical assays, did not deviate more than 2% from the values published by the NRC (2012).

Growth Performance

Mortality ranged from 1.9% to 3.5% and was not related to treatment.

On d 0 and 21, pig BW was not different among treatments (Table 5). At d 42 and d 63, pigs fed the ME- based diets (ME-D and ME-DC) were lighter than pigs fed the CTL diet ($P < 0.05$). Pigs fed NE-D had a BW similar to those fed the CTL diet while pigs fed NE-DC lighter ($P < 0.05$). On d 84 and at harvest, there were no differences in BW among treatments ($P > 0.10$).

In the first growth phase (d 0 to 21), pigs fed ME-D, NE-D and ME-DC diets maintained the same ADG as the pigs on the CTL diet (Table 6). Only pigs fed the NE-DC diet gained less than pigs fed the CTL diet ($P < 0.05$). On the other hand, ADFI was lower in pigs fed ME-DC and NE-DC diets than pigs fed the CTL diet ($P < 0.05$). Pigs fed ME-D as well as the pigs fed both NE-based diets showed no difference in G:F ratio compared with the control while those fed the ME-DC had a better G:G ratio ($P < 0.05$). This suggests that the energy values associated with corn germ meal may have been underestimated.

In the second growth phase, pigs fed both of the ME-based diets, as well as those fed the NE-DC diet, lower ADG compared to pigs fed the CTL diet ($P > 0.05$). In contrast, pigs fed the NE-D diet maintained an ADG similar to that of pigs on the CTL diet. Pigs fed ME-DC and NE-DC diets ate less feed than those on the CTL diet ($P < 0.05$), while feed intake of pigs fed ME-D or NE-D was similar to that of the CTL diet. Finally, G: F ratio was not different among dietary treatments.

In the third growth phase, as well as for the overall experiment, ADG, ADFI and G:F ratio were not different among treatments.

There were no interactions between sex and treatment for any growth performance variable.

Carcass Data

Pigs fed the ME-D, ME-DC and NE-DC diets had lower HCW and dressing percentage compared with those fed the CTL diet (Table 7; $P < 0.05$). However, pigs fed the NE-D diet maintained a similar HCW and dressing percentage as those on the CTL diet. Total carcass gain was lower in pigs fed with ME-D, ME-DC and NE-DC diets compared with those fed the CTL or the NE-D diets ($P < 0.05$). Carcass ADG was lower in pigs fed the ME-D, ME-DC and NE-DC diets compared with those fed the CTL diet ($P < 0.05$). Carcass gain of the pigs fed the NE-D diet was similar to that of pigs fed the CTL diet. Carcass G:F ratio was not different among treatments.

Back fat depth was similar in pigs on the NE-D and the CTL diets (*P* < 0.05); however, it was lower for pigs fed ME-D, ME-DC and NE-DC compared with those on the CTL diet (*P* < 0.05). Loin depth was similar in pigs fed ME-D and NE-D and the CTL diet, but pigs fed ME-DC and NE-DC diets had less loin depth compared with those fed the CTL diet (*P* < 0.05). There were no differences in FOM lean percentage among all treatments. Carcass ADG of lean tissue was similar in pigs fed ME-D and NE-D and the CTL diet, but pigs fed ME-DC and NE-DC diets had lower carcass ADG of lean tissue compared with those fed the CTL diet (P < 0.05). There were no interactions between sex and treatment for any carcass parameter.

Energy Intake and Efficiency

In the first growth phase, daily intake of ME or NE was lower in pigs fed the ME-DC and NE-DC diets than those fed the CTL diet (Table 8; *P* < 0.05). Pigs fed these diets needed less energy (ME or NE) per kg of BW than those fed the CTL diet (*P* < 0.05). In contrast, pigs on the ME-D and NE-D diets consumed the same quantity of ME or NE as the pigs fed the CTL diet and used the same amount of ME or NE per kg of BW gain.

In the second phase, average daily NE intake was lower in pigs fed ME-DC and NE-DC diets than those fed the CTL diet (*P* < 0.05), while pigs on ME-D and NE-D diets maintained a similar NE intake compared with those fed the CTL diet. NE per kg of BW was not different among treatments. Average daily ME intake tended to be lower in pigs fed ME-DC than those fed the CTL diet (*P* < 0.10), while pigs fed NE-DC, ME-D and NE-D had similar average daily ME intake compared with those fed the CTL diet. Calculated ME per kg of BW was greater in pigs fed ME-D and NE-D diets than those fed the CTL diet (*P* < 0.05), while pigs on ME-DC and NE-DC diets were similar in terms of ME per kg of BW compared with the CTL diet.

In the third phase there were no differences among treatments for average daily energy intake or for efficiency of energy utilization (P > 0.10).

For the overall period, average daily NE intake was lower in pigs fed ME-DC compared with those fed the CTL diet ($P < 0.05$), while pigs fed ME-D, NE-D and NE-DC ate the same quantity of NE compared with those fed the CTL diet. Calculated NE_m was not different among treatments. In contrast, calculated NE available for growth was lower for pigs fed ME-DC and NE-DC treatments compared with those fed the CTL diet ($P < 0.05$), while those fed ME-D, NE-D and CTL had similar NE available for growth.

Calculated NE per kg of BW was lower on pigs fed the ME-D, ME-DC and NE-DC treatments compared with those fed the CTL diet ($P < 0.05$), while those fed NE-D and the CTL utilized the same quantity of NE per kg of BW. NE consumed per kg of carcass weight was not different among treatments. Average daily ME intake, ME_m or ME consumed per kg of BW were not different among treatments. Although ME for growth was not different between pigs fed the CTL diets than the rest of the treatments, it was higher for pigs fed NE-D compared with those fed ME-DC and NE-DC diets ($P < 0.05$).

Calculated ME per kg of carcass was higher in pigs fed ME-D and NE-D than in those fed the CTL diet ($P < 0.05$), while pigs fed ME-DC and NE-D needed a similar quantity of ME consumed per kg of BW compared with those fed the CTL diet. There were no interactions between sex and treatment for any energy intake and efficiency variables.

DISCUSSION

A feeding program is effective when a change in ingredient composition has no unexpected effect on animal growth performance (Blaxter and Boyne, 1978; Ferrell and Oltjen, 2008; Beaulieu et al., 2009; Schinckel et al., 2012). In order to achieve such predictable outcomes, quantifying the energy content of ingredients and mixed feed is essential. Although there is a need for more mechanistic models that overcome the weaknesses of the classical energy partition approach (Birkett and de Lange, 2001), there may be an opportunity for ME system users to improve performance predictability upon the adoption of the NE system. As reported herein, the values from the assay of the ingredients not only supported the calculation of NE concentrations, but also confirmed strong agreement between published values (NRC, 2012) for ingredients, diets and values calculated using the Noblet (1994) equation. This is not at all surprising, given that the equations used herein were the same as those used by the NRC (2012). The concurrence between the NE values for ingredients used herein and the values reported by the NRC (2012) reflect the similarly in chemical composition of the ingredients.

Results from the first 2 dietary phases indicated a reduced ADFI in pigs fed isocaloric (ME or NE) diets containing corn DDGS and corn germ meal. Although no detrimental effects on growth performance have been reported feeding up to 30% corn DDGS (Stein and Shurson, 2009; Stein, 2011; Weber et al., 2015), and 38% corn germ meal (Weber et al., 2010), lower initial feed intake can occur on higher fiber diets (Weber et al., 2010; Jha et al., 2013). This effect is mainly attributed to a limited gut capacity in the pig (Bach, Knudsen and Hansen, 1991; Nyachoti et al., 2004; Zhang et al., 2013), or possibly a decrease in palatability (Solà-Oriol et al., 2011). In any event, maintaining NE or ME concentration at the same level of a corn-soybean meal diet cannot result in equal growth performance if feed intake is compromised. An alternative approach, energy intake per kg gain rather than feed intake, may be a more reliable measurement, assuming that no other factors are limiting growth. This approach provides another way to compare ME and NE systems, rather than relying on the use of theoretically isocaloric diets.

While feed intake depression on higher fiber diets is a serious limitation, and obviously prevents equal growth, this may be a temporary problem. Heavier pigs have greater gastrointestinal capacity, facilitating a greater volume of feed intake and therefore a more successful adaptation to higher fiber diets (Kyriazakis and Emmans, 1995; Gutierrez et al., 2013). This was confirmed in the last phase of this experiment, where feed intake of pigs fed the higher fiber diets was similar to pigs fed the corn-soybean meal diet.

Despite differences within the first two phases, growth performance combined over the three dietary phases (0 to 94 d) was similar regardless of dietary treatment. Therefore, a corn-soybean meal diet (basically a diet higher in starch and lower in fat and fiber) can be effectively replaced with diets containing co-products (lower in starch and higher in fiber content) under commercial conditions. With comparable overall growth performance observed across all diets for the duration of this study, it is reasonable to conclude that the ME and NE values for the diets were quite accurate. However, this also suggests that growth performance variables *per se* (at least under the conditions of this experiment) may not be the best option to explain differences between ME and NE systems.

In this experiment, similar growth performance between high co-product ME diets and their NE counterparts may be the result of very similar NE:ME ratios among diets. Despite adding up to 40% of co-product ingredients into the diet, the NE:ME ratio remained fairly constant (0.73-0.75) among the 5 dietary treatments. The inclusion of co-products normally results in a lower NE:ME ratio because the individual ratios of these ingredients are lower than for corn (Noblet, 1994). However, in this study, the addition of choice white grease kept the ratios quite similar. In fact, the main difference between the NE and the ME diets was the quantity of the added fat, which was greater when formulated with the NE system than the ME system. This difference is the result of the greater discount given to fiber in the NE as compared to the ME system (Noblet, 1994; Moehn et al, 2005). Since the NE:ME ratios were narrow, the pressure placed on the two systems was not greater than one would see in commercial practice. Indeed, this is an argument often used by feed companies transitioning to the NE system; if the NE:ME ratio varies only slightly, the risk of disappointing performance is quite low. One could also argue that dietary treatments with wider NE:ME ratios would have provided a better test of the NE system.

Carcass results showed that NE formulations were effective in predicting the outcomes, especially in terms of dressing percentage when corn DDGS were added to a corn-soybean meal diet, but were less effective when both corn DDGS and corn germ were included. In contrast, formulations under the ME system were not successful in maintaining a constant dressing percentage. Inconsistent dressing percentage data have been reported in pigs fed different levels of corn DDGS (NRC, 2012). Widmer et al. (2008) and Xu et al. (2008) reported no effect of fibrous ingredients on dressing percentage while Cook et al. (2005), Whitney et al. (2006), Linneen et al. (2008) and Weber et al. (2015) observed a lower dressing percentage. A lower dressing percentage in pigs fed high fiber diets is usually related to hypertrophic effects on the gastrointestinal tract (Anugwa et al., 1989; Pond et al., 1989; Kerr and Shurson, 2013). However, little to no attention has been attributed to the energy supply. This is important to note when highly fibrous ingredients are included. Results from the NE treatment with added corn DDGS suggest that dressing percentages may be less affected with an equal dietary energy concentration. This was not the case when corn germ meal was used, suggesting the NE value for this ingredient may have been incorrect.

Energy intake and efficiency of energy utilization are alternative options for evaluating growth performance and carcass characteristics. These parameters have at least two important advantages compared to the traditional growth and carcass performance evaluation. First, energy intake and efficiency of energy utilization describe the feed supply in terms of energy rather than weight (Patience, 2012; Schinckel et al, 2012). Second, they allow for evaluation of all diets in terms of NE or ME, regardless of the energy system used in the formulation, facilitating NE and ME comparisons from a different perspective. The role of the energy system is to describe energy utilization accurately; thus, energy intake should explain energy retention. For each dietary phase, NE and ME intake and efficiency were consistent with the whole BW performance results, except for phase 2, where ME/kg of BW gain was higher for diets including corn DDGS compared with the CTL diet.

Energy intake and the efficiency of energy utilization over the total length of the study were perhaps the most relevant variables for evaluation of the differences between the ME and the NE systems. Results based on the NE system suggest that lower energy intakes are most likely to occur on the most complex diets. Calculated NE for growth confirmed that when NE is partitioned between maintenance and growth, there is less energy available for retention on these more complex diets; it also confirmed that when applying calculated NE, maintenance is similar among treatments.

Although the NE system identified different energy efficiencies at the whole body level, this variable could be influenced by additional weight of the intestinal contents. High fiber diets can add up to 38% more weight to the viscera (Lorschy et al., 1997; de Lange et al., 2003), ultimately overestimating their energy efficiency. Net energy efficiency was similar among diets at the carcass level; therefore, the possibility of BW being influenced by greater intestinal contents in pigs fed high fiber diets seems to be reasonable.

On the other hand, the ME system provided contradictory results. Although ME intake and ME for maintenance were not different among treatments, the quantity of ME available for growth was different among treatments. This may suggest that ME is less sensitive than the NE system in detecting differences in energy intake, which is fundamental in explaining energy retention. Although ME efficiency at the whole BW level was similar among treatments, ME efficiencies for carcass gain were different. Since ME is suggesting similar intakes, similar carcass gain would have also been expected.

In conclusion, the sequential addition of co-products in diets formulated on an NE or ME basis can result in similar growth performance; as greater quantities of co-products are used, in this instance 40%, small reductions may be observed. However, the addition of co-product ingredients, especially high fiber ingredients, can also affect carcass characteristics. In this instance, diets formulated using the NE system seemed to be more robust than those formulated using the ME system where carcass parameters were concerned. Finally, calculations of caloric efficiency indicated that the NE system was better at predicting retained energy at the carcass level than the ME system in high fiber diets. Overall, we conclude that the NE system, based on NRC 2012 estimates, did a slightly better job than ME in predicting energy used for the support of growth. However, the advantages are very small. Looked at from the opposite perspective, pigs fed diets based on the NE system did not underperform those fed the ME-based diets, suggesting that converting to NE from ME has little risk. As stated previously, the purposes of energy systems are to facilitate diet formulation and to serve as a basis for assigning relative economic values to ingredients. In this study, the benefit of the NE system accruing from the first role is modest. Depending on the relative cost of ingredients, the financial benefit to the adoption of NE may be considerably greater in the second role – the relative pricing of ingredients.

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Table 1. Ingredient inclusion and chemical and nutritional characteristics of phase 1 diets (as-fed basis[1]).

Item	CTL[2]	ME-D[3]	NE-D[4]	ME-DC[5]	NE-DC[6]
Ingredient, %					
Corn	59.50	47.67	47.22	37.02	36.77
Soybean meal	35.20	22.00	22.00	20.00	20.00
Choice white grease	3.00	2.75	3.20	5.20	5.45
Corn DDGS, >10% oil		25.00	25.00	15.00	15.00
Corn germ meal				20.00	20.00
Limestone, ground	0.89	1.25	1.24	1.17	1.17
Monocalcium phosphate	0.71	0.18	0.18	0.41	0.41
Salt	0.43	0.43	0.43	0.43	0.43
Vitamin premix	0.10	0.10	0.10	0.10	0.10
L-Lysine HCl	0.10	0.40	0.40	0.41	0.41
DL-Methionine	0.05			0.02	0.02
L-Threonine	0.02	0.04	0.04	0.05	0.05
L-Tryptophan		0.04	0.04	0.04	0.04
Choline chloride, 60% dry	0.02	0.02	0.02	0.02	0.02
Iron oxide, red		0.15		0.15	
Iron oxide, black			0.15		0.15
Diet composition					
ME, Mcal/kg	3.43	3.45	3.47	3.44	3.47
NE, Mcal/kg	2.54	2.53	2.55	2.53	2.54
NE:ME ratio	0.74	0.73	0.74	0.73	0.74
Starch, %	37.26	30.55	30.27	27.73	27.58
NDF, %	9.68	16.68	16.62	21.49	21.47
ADF, %	3.02	5.00	4.98	5.94	5.94
Ether extract, %	4.81	6.76	7.20	8.26	8.50
Crude protein, %	21.27	21.19	21.14	21.33	21.31
Lysine, %	1.27	1.29	1.29	1.32	1.32
SID Lys, %	1.15	1.15	1.15	1.15	1.15
SID AA: Lys ratio					
Thr	0.62	0.61	0.61	0.61	0.62
Trp	0.21	0.19	0.19	0.19	0.19
Met+ Cys	0.57	0.61	0.61	0.58	0.58
Calcium, %	0.68	0.68	0.68	0.68	0.68
Total phosphorus, %	0.61	0.55	0.55	0.57	0.57
STTD phosphorus, %	0.29	0.29	0.29	0.29	0.29

[1]Dietary treatments delivered in meal form from 0-21d.

[2]CTL = corn-soybean meal based diet.

[3]ME-D = control plus 25% of corn DDGS, ME equal to the corn-soybean meal diet.

[4]NE-D = control plus 25% of corn DDGS, NE equal to the corn-soybean meal diet.

[5]ME-DC = control plus 15% of corn DDGS and 20% of corn germ meal, ME equal to the corn-soybean meal diet.

[6]NE-DC = control plus 15% each of corn DDGS and 20% of corn germ meal, NE equal to the corn-soybean meal diet.

Table 2. Ingredient inclusion and chemical and nutritional characteristics of phase 2 diets (as-fed basis[1]).

Item	CTL[2]	ME-D[3]	NE-D[4]	ME-DC[5]	NE-DC[6]
Ingredient, %					
Corn	63.78	49.34	48.69	38.39	37.94
Soybean meal	31.05	15.5	15.55	13.8	13.85
Choice white grease	3.00	2.65	3.25	5.15	5.55
Corn DDGS, >10% oil		30.00	30.00	20.00	20.00
Corn germ meal				20.00	20.00
Limestone, ground	0.90	1.30	1.30	1.30	1.30
Monocalcium phosphate	0.73	0.10	0.10	0.32	0.32
Salt	0.40	0.40	0.40	0.40	0.40
Vitamin premix	0.10	0.10	0.10	0.10	0.10
L-Lysine HCl		0.35	0.35	0.35	0.35
L-Threonine		0.02	0.02	0.02	0.02
L-Tryptophan		0.03	0.03	0.03	0.03
Iron oxide, red		0.15		0.15	
Iron oxide, black			0.15		0.15
Diet composition					
ME, Mcal/kg	3.43	3.45	3.48	3.45	3.47
NE, Mcal/kg	2.56	2.55	2.57	2.55	2.56
NE:ME ratio	0.75	0.74	0.74	0.74	0.74
Starch, %	39.84	31.64	31.24	28.64	28.36
NDF, %	9.90	18.29	18.21	23.09	23.04
ADF, %	2.93	5.30	5.29	6.26	6.25
Ether extract, %	4.89	7.19	7.78	8.72	9.11
Crude protein, %	19.65	19.65	19.63	19.92	19.91
Lysine, %	1.08	1.11	1.11	1.14	1.14
SID Lys, %	0.97	0.97	0.97	0.97	0.97
SID AA: Lys ratio					
Thr	0.67	0.65	0.65	0.64	0.64
Trp	0.22	0.19	0.19	0.20	0.20
Met+ Cys	0.59	0.71	0.71	0.66	0.66
Calcium, %	0.68	0.68	0.68	0.68	0.68
Total phosphorus, %	0.59	0.53	0.52	0.55	0.55
STTD phosphorus, %	0.29	0.29	0.29	0.29	0.29

[1]Dietary treatments delivered in meal form from 21-42d.

[2]CTL = corn-soybean meal based diet.

[3]ME-D = control plus 30% of corn DDGS, ME equal to the corn-soybean meal diet.

[4]NE-D = control plus 30% of corn DDGS, NE equal to the corn-soybean meal diet.

[5]ME-DC = control plus 20% of corn DDGS and 20% of corn germ meal, ME equal to the corn-soybean meal diet.

[6]NE-DC = control plus 20% each of corn DDGS and 20% of corn germ meal, NE equal to the corn-soybean meal diet.

Table 3. Ingredient inclusion and chemical and nutritional characteristics of phase 3 diets (as-fed basis[1]).

Item	CTL[1]	ME-D[2]	NE-D[3]	ME-DC[4]	NE-DC[5]
Ingredient, %					
Corn	70.11	51.05	49.75	40.88	39.98
Soybean meal	25.30	14.55	14.75	12.05	12.15
Choice white grease	2.50	2.20	3.30	4.70	5.50
Corn DDGS, >10% oil		30.00	30.00	20.00	20.00
Corn germ meal				20.00	20.00
Limestone, ground	0.90	1.30	1.30	1.20	1.20
Monocalcium phosphate	0.68			0.25	0.25
Salt	0.40	0.40	0.40	0.40	0.40
Vitamin premix	0.10	0.10	0.10	0.10	0.10
L-Lysine HCl		0.23	0.23	0.23	0.23
L-Tryptophan		0.02	0.02	0.02	0.02
Iron oxide, red		0.15		0.15	
Iron oxide, black			0.15		0.15
Diet composition					
ME, Mcal/kg	3.42	3.43	3.48	3.43	3.47
NE, Mcal/kg	2.58	2.54	2.58	2.54	2.57
NE:ME ratio	0.75	0.74	0.74	0.74	0.74
Starch, %	43.66	32.68	31.88	30.15	29.59
NDF, %	10.25	18.43	18.28	23.26	23.16
ADF, %	2.80	5.30	5.28	6.23	6.22
Ether extract, %	4.52	6.78	7.85	8.33	9.10
Crude protein, %	17.42	19.34	19.33	19.29	19.27
Lysine, %	0.93	0.98	0.98	0.99	0.99
SID Lys, %	0.83	0.85	0.85	0.83	0.83
SID AA: Lys ratio					
Thr	0.69	0.71	0.71	0.70	0.70
Trp	0.22	0.20	0.20	0.20	0.20
Met+ Cys	0.63	0.80	0.79	0.76	0.75
Calcium, %	0.64	0.64	0.64	0.64	0.64
Total phosphorus, %	0.56	0.50	0.50	0.53	0.53
STTD phosphorus, %	0.27	0.27	0.27	0.27	0.27

[1]Dietary treatments delivered in meal form from 42-94d.

[2]CTL = corn-soybean meal based diet.

[3]ME-D = control plus 30% of corn DDGS, ME equal to the corn-soybean meal diet.

[4]NE-D = control plus 30% of corn DDGS, NE equal to the corn-soybean meal diet.

[5]ME-DC = control plus 20% of corn DDGS and 20% of corn germ meal, ME equal to the corn-soybean meal diet.

[6]NE-DC = control plus 20% each of corn DDGS and 20% of corn germ meal, NE equal to the corn-soybean meal diet.

Table 4. Analyzed ingredient composition and calculation of NE for the ingredients utilized in the experimental diets (as-fed basis).

Ingredient	Corn	Corn germ meal	Corn DDGS	Soybean meal
Composition, %				
Dry matter	86.70	89.16	89.70	89.70
Crude protein	7.82	23.79	28.26	47.21
Ether extract	2.65	1.90	10.45	0.66
Starch	61.72	20.52	3.15	1.53
ADF	2.30	12.17	11.46	4.70
NDF	12.04	49.94	37.46	7.16
NE, Mcal/kg				
Calculated[1]	2.67	1.91	2.35	2.07
NRC, 2012 table	2.67	1.89	2.38	2.09

[1] From NRC 2012, equation [1-7].

Table 5. Impact of feeding diets formulated using the ME or the NE systems on the BW of growing pigs[1] (kg)

Day	CTL[1]	ME-D[2]	NE-D[3]	ME-DC[4]	NE-DC[5]	SEM	*P*-value
0	41.0	41.0	41.0	41.0	41.0	0.7	1.000
21	61.4	61.0	61.2	61.1	60.4	0.7	0.134
42	83.9[a]	82.9[bc]	83.3[ab]	82.6[bc]	82.2[c]	0.8	0.008
63	104.3[a]	103.1[b]	104.5[a]	102.9[b]	103.2[b]	0.9	0.052
84	123.5	122.3	123.7	121.6	122.2	1.0	0.135
Harvest BW	131.2	130.5	131.6	129.8	130.5	1.1	0.555

[a-c] Within a row, least square means without a common superscript letter differ ($P \leq 0.05$).

[1]CTL = corn-soybean meal based diet.

[2]ME-D = control plus 30% of corn DDGS (25% for phase 1), ME equal to the corn-soybean meal diet.

[3]NE-D = control plus 30% of corn DDGS, (25% for phase 1) NE equal to the corn-soybean meal diet.

[4]ME-DC = control plus 20% each of corn DDGS and corn germ meal, (15 and 20% respectively for phase 1), and ME equal to the corn-soybean meal diet.

[5]NE-DC = control plus 20% each of corn DDGS and corn germ meal, (15 and 20% respectively for phase 1), and NE equal to the corn-soybean meal diet.

Table 6. Whole body growth performance of pigs fed diets containing varying levels of co-product ingredients and formulated using the ME or the NE system[1]

Item	CTL[1]	ME-D[2]	NE-D[3]	ME-DC[4]	NE-DC[5]	SEM	*P*-value
Phase 1, (0-21d)							
ADG, kg	0.968[a]	0.953[ab]	0.963[a]	0.956[ab]	0.924[b]	0.012	0.084
ADFI, kg	2.208[a]	2.179[a]	2.207[a]	2.114[b]	2.059[b]	0.025	<0.001
G:F ratio	0.438[ab]	0.437[ab]	0.436[a]	0.453[c]	0.450[bc]	0.006	0.026
Phase 2, (21-42d)							
ADG, kg	1.073[a]	1.040[b]	1.049[ab]	1.024[b]	1.037[b]	0.010	0.004
ADFI, kg	2.747[a]	2.697[ab]	2.722[ab]	2.645[b]	2.654[b]	0.031	0.072
G:F ratio	0.391	0.387	0.386	0.389	0.391	0.004	0.786
Phase 3, (42-Market, BW)							
ADG, kg	0.966	0.984	0.976	0.964	0.974	0.016	0.895
ADFI, kg	2.991	2.990	2.998	2.940	2.961	0.041	0.797
G:F ratio	0.323	0.330	0.326	0.329	0.329	0.004	0.713
Overall (0-Market, BW)							
ADG, kg	0.955	0.953	0.963	0.945	0.946	0.009	0.581
ADFI, kg	2.760	2.742	2.758	2.688	2.688	0.031	0.177
G:F ratio	0.346	0.349	0.350	0.352	0.353	0.002	0.187
Mortality, %	2.75	2.16	2.17	1.89	3.48	0.72	0.540

[a-c] Within a row, least squares means without a common superscript letter differ ($P \leq 0.05$)

[1]CTL = corn-soybean meal based diet.

[2]ME-D = control plus 30% of corn DDGS (25% for phase 1), ME equal to the corn-soybean meal diet.

[3]NE-D = control plus 30% of corn DDGS, (25% for phase 1) NE equal to the corn-soybean meal diet.

[4]ME-DC = control plus 20% each of corn DDGS and corn germ meal, (15 and 20% respectively for phase 1), and ME equal to the corn-soybean meal diet.

[5]NE-DC = control plus 20% each of corn DDGS and corn germ meal, (15 and 20% respectively for phase 1), and NE equal to the corn-soybean meal diet.

Table 7. Carcass characteristics of pigs fed diets containing varying levels of co-product ingredients and formulated using the ME or the NE system[1]

Item	CTL[1]	ME-D[2]	NE-D[3]	ME-DC[4]	NE-DC[5]	SEM	*P*-value
HCW, kg	97.0[a]	95.3[bc]	96.7[ab]	94.6[c]	95.3[bc]	0.8	0.016
Dressing, %	74.0[a]	73.1[bc]	73.6[ab]	72.8[c]	73.1[bc]	0.2	0.001
Carcass gain, kg	66.7[a]	65.0[b]	66.3[a]	64.2[b]	65.0[b]	0.6	0.014
Carcass ADG, kg/d	0.712[a]	0.694[bc]	0.708[ab]	0.686[c]	0.694[bc]	0.007	0.018
Carcass G:F ratio	0.258	0.254	0.257	0.256	0.259	0.001	0.109
FOM back fat depth, mm	21.7[a]	20.6[b]	21.3[ab]	20.9[b]	20.7[b]	0.4	0.010
FOM loin depth, mm	60.2[a]	59.3[abc]	59.6[ab]	58.4[c]	58.6[bc]	0.4	0.010
FOM lean, %	51.8	52.1	51.8	51.9	51.9	0.1	0.433
Carcass ADG of lean, kg	0.368[a]	0.361[abc]	0.367[ab]	0.355[c]	0.360[bc]	0.005	0.011

[a-c] Within a row, least squares means without a common superscript letter differ ($P \leq 0.05$)
[1]CTL = corn-soybean meal based diet.
[2]ME-D = control plus 30% of corn DDGS (25% for phase 1), ME equal to the corn-soybean meal diet.
[3]NE-D = control plus 30% of corn DDGS, (25% for phase 1) NE equal to the corn-soybean meal diet.
[4]ME-DC = control plus 20% each of corn DDGS and corn germ meal, (15 and 20% respectively for phase 1), and ME equal to the corn-soybean meal diet.
[5]NE-DC = control plus 20% each of corn DDGS and corn germ meal, (15 and 20% respectively for phase 1), and NE equal to the corn-soybean meal diet.

Table 8. Energy intake and efficiency of pigs fed diets containing varying levels of co-product ingredients and formulated using the ME or the NE system (as-fed basis) [1]

Item	CTL[1]	ME-D[2]	NE-D[3]	ME-DC[4]	NE-DC[5]	SEM	*P*-value
Phase 1, Mcal/d							
NE intake	5.61[a]	5.52[a]	5.63[a]	5.35[b]	5.23[b]	0.06	<0.001
NE per kg of BW gain	5.79[a]	5.74[ab]	5.85[a]	5.59[c]	5.61[bc]	0.05	0.001
ME intake	7.57[a]	7.51[a]	7.65[a]	7.28[b]	7.11[b]	0.09	<0.001
ME per kg of BW gain	7.81[ab]	7.81[ab]	7.95[a]	7.61[c]	7.63[bc]	0.07	0.003
Phase 2, Mcal/d							
NE intake	7.04[a]	6.87[abc]	7.01[ab]	6.74[c]	6.80[bc]	0.08	0.020
NE per kg of BW gain	6.50	6.60	6.67	6.56	6.55	0.05	0.197
ME intake	9.50[a]	9.34[ab]	9.50[a]	9.15[b]	9.23[ab]	0.11	0.082
ME per kg of BW gain	8.70[b]	8.93[a]	9.02[a]	8.89[ab]	8.86[ab]	0.07	0.039
Phase 3, Mcal/d							
NE intake	7.71	7.58	7.75	7.46	7.62	0.11	0.279
NE per kg of BW gain	8.02	7.73	7.96	7.75	7.84	0.10	0.158
ME intake	10.22	10.26	10.44	10.08	10.27	0.14	0.441
ME per kg of BW gain	10.63	10.45	10.74	10.46	10.56	0.13	0.553
Overall period, Mcal/d							
NE intake.	7.08[ab]	6.96[abc]	7.10[a]	6.82[c]	6.89[bc]	0.08	0.035
NE_m[6]	2.68	2.67	2.69	2.65	2.66	0.02	0.294
NE for growth[7]	4.40[a]	4.29[ab]	4.41[a]	4.17[b]	4.23[b]	0.06	0.025
NE per kg of BW gain	7.42[a]	7.29[bc]	7.37[ab]	7.21[c]	7.28[bc]	0.04	0.010
NE per kg of carcass gain	9.94	10.01	10.02	9.94	9.93	0.06	0.640
ME intake	9.45	9.43	9.59	9.24	9.31	0.11	0.112
ME_m[8]	3.84	3.84	3.85	3.81	3.82	0.02	0.596
ME for growth[9]	5.67[ab]	5.63[ab]	5.78[a]	5.45[b]	5.52[b]	0.09	0.067
ME per kg of BW gain	9.90	9.89	9.96	9.76	9.84	0.06	0.188
ME per kg of carcass gain	13.26[a]	13.57[b]	13.54[b]	13.45[ab]	13.41[ab]	0.08	0.048

[a-c] Within a row, least squares means without a common superscript letter differ ($P \leq 0.05$)

[1]CTL = corn-soybean meal based diet.

[2]ME-D = control plus 30% of corn DDGS (25% for phase 1), ME equal to the corn-soybean meal diet.

[3]NE-D = control plus 30% of corn DDGS, (25% for phase 1) NE equal to the corn-soybean meal diet.

[4]ME-DC = control plus 20% each of corn DDGS and corn germ meal, (15 and 20% respectively for phase 1), and ME equal to the corn-soybean meal diet.

[5]NE-DC = control plus 20% each of corn DDGS and corn germ meal, (15 and 20% respectively for phase 1), and NE equal to the corn-soybean meal diet.

[6]Calculated as NEm (kcal/d) = $(FHP \times 0.708+207) \times (BW, kg)^{0.6}$ (van Milgen et al., 2008)

[7]Calculated as NE for growth = NE intake - NE_m.

[8]Calculated as MEm = 197× (BW, kg) $^{0.60}$ (NRC, 2012).
[9]Calculated as ME for growth = ME intake – MEm.