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Nonsolar energy use and one-hundred-year global warming potential of Iowa swine feedstuffs and feeding strategies

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Abstract

Demand for nonsolar energy and concern about the implications of fossil fuel combustion have encouraged examination of energy use associated with agriculture. The United States is a global leader in pig production, and the United States swine industry is centered in Iowa. Feed is the largest individual input in pig production, but the energy consumption of the Iowa swine feed production chain has yet to be critically examined. This analysis examines nonsolar energy use and resulting 100-yr global warming potential (GWP) associated with the swine feed production chain, beginning with cultivation of crops and concluding with diet formulation. The nonsolar energy use and accompanying 100-yr GWP associated with production of 13 common swine feed ingredients are estimated. Two diet formulation strategies are considered for 4 crop sequence × ingredient choice combinations to generate 8 crop sequence × diet formulation scenarios. The first formulation strategy (simple) does not include synthetic AA or phytase. The second strategy (complex) reduces CP content of the diet by using L-lysine to meet standardized ileal digestibility lysine requirements of pigs and includes the exogenous enzyme phytase. Regardless of crop sequence × diet formulation scenario, including the enzyme phytase is energetically favorable and reduces the potential excretion of P by reducing or removing inorganic P from the complete diet. Including L-lysine reduces the CP content of the diet and requires less nonsolar energy to deliver adequate standardized ileal digestible lysine than simply feeding soybean meal. Replacing soybean meal with full-fat soybeans is not energetically beneficial under Iowa conditions. Swine diets including dried distillers grains with solubles and crude glycerol require approximately 50% more nonsolar energy inputs than corn-soybean meal diets or corn-soybean meal diets including oats. This study provides essential information on cultivation, processing, and manufacture of swine feed ingredients in Iowa that can be coupled with other models to estimate the nonsolar energy use and 100-yr GWP of pig production.

Keywords

Animal Science, Economics, crop production, feed processing, swine feedstuff

Disciplines

Agricultural and Resource Economics | Agricultural Economics | Agriculture | Animal Sciences | Bioresource and Agricultural Engineering | Economics

Comments

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Nonsolar energy use and one-hundred-year global warming potential of Iowa swine feedstuffs and feeding strategies[1]

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ABSTRACT: Demand for nonsolar energy and concern about the implications of fossil fuel combustion have encouraged examination of energy use associated with agriculture. The United States is a global leader in pig production, and the United States swine industry is centered in Iowa. Feed is the largest individual input in pig production, but the energy consumption of the Iowa swine feed production chain has yet to be critically examined. This analysis examines nonsolar energy use and resulting 100-yr global warming potential (GWP) associated with the swine feed production chain, beginning with cultivation of crops and concluding with diet formulation. The nonsolar energy use and accompanying 100-yr GWP associated with production of 13 common swine feed ingredients are estimated. Two diet formulation strategies are considered for 4 crop sequence × ingredient choice combinations to generate 8 crop sequence × diet formulation scenarios. The first formulation strategy (simple) does not include synthetic AA or phytase. The second strategy (complex) reduces CP content of the diet by using L-lysine to meet standardized ileal digestibility lysine requirements of pigs and includes the exogenous enzyme phytase. Regardless of crop sequence × diet formulation scenario, including the enzyme phytase is energetically favorable and reduces the potential excretion of P by reducing or removing inorganic P from the complete diet. Including L-lysine reduces the CP content of the diet and requires less nonsolar energy to deliver adequate standardized ileal digestible lysine than simply feeding soybean meal. Replacing soybean meal with full-fat soybeans is not energetically beneficial under Iowa conditions. Swine diets including dried distillers grains with solubles and crude glycerol require approximately 50% more nonsolar energy inputs than corn-soybean meal diets or corn-soybean meal diets including oats. This study provides essential information on cultivation, processing, and manufacture of swine feed ingredients in Iowa that can be coupled with other models to estimate the nonsolar energy use and 100-yr GWP of pig production.

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INTRODUCTION

Feed is the largest individual input in pig production systems. In the United States, pig diets are complete formulated mixes of several different ingredients, primarily corn and soybean meal (**SBM**). Iowa leads the United States in pork production as well as cultivation of corn and soybeans (USDA, 2009). Recently, production of biofuels, fuel grade ethanol from carbohydrates, and monoakyl esters for biodiesel from lipids has rapidly increased in the United States and Iowa (NBB, 2008; RFA, 2009).

Processing grains and oilseeds into feed ingredients commonly fed to pigs require different techniques and energy inputs. Feed ingredients, such as corn and oats, are typically ground but generally require little additional manipulation. Other raw materials such as soybeans require multistep processes to produce SBM and soy oil. In Iowa, ground corn and SBM account for ≥95% of the mass of swine diets. Growth in production of ethanol from corn grain and biodiesel from soy oil have increased the use of biofuel coproducts, particularly dried distillers grains with solubles (**DDGS**) and to a lesser extent crude glycerol in pig diets. Crude glycerol is a coproduct of biodiesel production, and DDGS is a coproduct of ethanol production.

With increasing attention being paid to energy in all aspects of agriculture, it is appropriate to reexam-

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ine the production of different swine feed ingredients and the potential impacts of different diet formulation strategies. Our analysis begins with cultivation of crops and includes ingredient processing and manufacture as well as final diet formulation. This project examines different crop production scenarios, processes for preparing diet ingredients, and efficacy of various formulation strategies to minimize nonsolar energy use and 100-year global warming potential (**GWP**) from emissions associated with production of swine feed.

MATERIALS AND METHODS

Animal Care and Use Committee approval was not obtained for this study because it is a modeling project based on previous published work and no animals were used.

Crop Production

A crop production model for Iowa was developed and used to evaluate nonsolar energy use by different crop sequence scenarios (Lammers, 2009). Three main types of nonsolar energy inputs were considered: diesel fuel, liquefied petroleum gas, and electricity. The model calculates nonsolar energy use based on physical material flows related to crop production. Direct consumption of fuels such as diesel fuel for field operations, liquefied petroleum gas for drying grain, and electricity for aeration of stored grain was calculated for each activity relating to crop production, transport, and storage. The energy required to produce key crop-production inputs that would be produced only if actual crop production occurred, seed, fertilizers, and pesticides, for example, was also included as indirect energy input. The energy required to produce the physical infrastructure and equipment used in crop production and storage, tractors, equipment, and storage bins, for example, was not considered.

Two crop sequences are compared in the present study. The first is corn-soybean (corn-soy) and is typical in Iowa and across the Midwest United States. The second sequence is an alternative of corn-soybean-corn-oat underseeded with a leguminous cover crop (corn-soy-corn-oat). Initial conditions and model assumptions for cultivation of different crop sequences were developed in consultation with Iowa farmers, Iowa State University researchers, extension publications, and peer-reviewed journal articles. The crop production model estimates nonsolar energy use of individual crops within a particular crop sequence, based on physical material flows, and is influenced by grain and oilseed production. The crop production model is not designed to accurately predict absolute values or impacts. Rather, the model is a functional representation of crop production in Iowa and can be used to predict the relative magnitude and direction of outcomes resulting from different actions and choices.

Gross energy represents the energy that could be gained by simply combusting all grain, oilseed, and biomass produced by a given crop sequence. Net energy represents the portion of GE that is available for a pig to use for growth and maintenance from a particular feedstuff (Ewan, 2001; Whittemore, 2006). Net energy most closely represents the true energy value of a feedstuff relative to pig production and is the energy value of most interest to swine nutritionists (Ewan, 2001; Whittemore et al., 2003; Whittemore, 2006). Starch concentration is another important measure of the suitability of a product for human food (Quezada-Cavillo et al., 2006) or pig feed (Sauber and Owens, 2001; Whittemore, 2006). Sauvant et al. (2004) presents the GE and NE available to pigs and the starch content of many feed ingredients. The GE of wheat straw is 16.9 MJ/kg, (91.4% DM; Sauvant et al., 2004), and our analysis assumes oat straw is equivalent to wheat straw. Corn stover was assumed to have a GE value of 14.2 MJ/kg at 15% moisture (Pordesimo et al., 2005). It was assumed that oat straw and corn stover are of very limited value as food or feedstuffs and that NE and starch content is effectively zero. Crop production model results and literature values were used to calculate GE and NE available to growing pigs and total starch production for each crop production sequence.

Feed Ingredient Processing and Manufacture

Feed ingredients, such as corn, require little manipulation beyond grinding. Alternatively, converting raw soybeans into SBM and soy oil requires multistep processes. An inventory of raw material inputs, processing activities, estimated transportation distances of material inputs and finished ingredients, and nonsolar energy use for 13 feed ingredients was prepared and has been detailed elsewhere (Lammers, 2009). This inventory is summarized in Table 1 and was used in combination with diet formulations to calculate nonsolar energy use and 100-yr GWP associated with manufacturing swine feed adequate to produce one 136.0-kg market pig. Primary feed ingredients, grains, SBM, and biofuel coproducts, typically account for ≥95% of the mass of pig diets. The remaining mass of the diet includes minerals, vitamins, synthetic AA, and enzymes. Our examination of the microfeed ingredients focuses on ground limestone, salt, and monocalcium phosphate (**MCP**) because these 3 ingredients account for most of the mass among microingredients. The enzyme phytase and synthetic AA L-lysine and DL-methionine are also included because they have an impact on P and N utilization and cycling within pig production systems that is disproportionate to their relative mass.

Table 1 reports the nonsolar energy use and resulting 100-yr GWP associated with producing and delivering 13 swine feed ingredients in Iowa. This inventory is not a complete life cycle assessment of swine feed, but can be linked with crop and pig production models to estimate the ecological impacts of raising pigs.

The last compilation of multiple swine feed ingredients was published in 1978 and was specific to Australia (LaHore and Croke, 1978). More recent examinations have considered 1 or 2 individual ingredients under European conditions (Binder, 2003; Nielsen and Wenzel, 2007; Nielsen et al., 2007; Dalgaard et al., 2008). The feed table included in this report is not a complete listing of all ingredients commonly fed in Iowa; however, it is a starting point for future examinations of nonsolar energy use associated with other swine feed ingredient production in Iowa and the United States and can be used for life cycle assessment of pig production in the Midwest United States.

Diet Formulation

Nutrition recommendations for swine in the United States are currently based on ME and apparent ileal digestible AA (NRC, 1998). A NE system considers the amount of heat lost during digestion and subsequent deposition of nutrients in body tissue and is thus a more accurate estimate of the true energy content of an ingredient (Ewan, 2001; Moehn et al., 2005; Noblet, 2007). Discussion of the practicality and application of a net energy system is ongoing among North American swine nutritionists (Moehn et al., 2005; Payne and Zijlstra, 2007; Zijlstra and Payne, 2008). At present standardized ileal digestibility (**SID**) is the most accurate basis for diet formulations in regards to AA availability (Gabert et al., 2001; Sauvant et al., 2004; Stein et al., 2007a,b). More recent European recommendations are based on NE and SID AA (Whittemore et al., 2003). Feedstuff tables presenting the NE and SID AA content of feed ingredients are available (Whittemore et al., 2003; Sauvant et al., 2004).

Seven diet formulations that have been demonstrated to be nutritionally adequate according to NRC recommendations (Holden et al., 1996; NRC, 1998; Lammers et al., 2008) were entered into a spreadsheet that recalculated nutritional content based on feed ingredient tables presented by Sauvant et al. (2004). Two reference diets were for adult animals, one for gestating sows and one for lactating sows (Holden et al., 1996). Five reference diets were for growing pigs and matched the corn-SBM control diets fed in phase from wean to market in a previous study (Lammers et al., 2008). Feed intake and estimated nutrient intake associated with production of one 136.0-kg market pig is presented as Table 2. The ratio of SID lysine to NE as well as the ratio of available P to NE were calculated from the reference diet formulations and used to reformulate a set of 7 baseline diets (simple) for this analysis. This set of diets does not include synthetic AA or exogenous enzymes.

Including synthetic AA and the enzyme phytase affects N and P utilization by the pig and affects the overall nutrient cycling of pig feed production. A second set of diets (complex) were formulated to include phytase and synthetic AA. The desired ratios of methionine, threonine, and tryptophan to NE for a given diet were calculated based on the ideal AA ratio concept (NRC, 1998; Lewis, 2001; Whittemore et al., 2003). Complex diets were first formulated to provide adequate methionine, threonine, and tryptophan. The synthetic AA L-lysine was then added as needed to provide adequate lysine. Feeding the enzyme phytase enables utilization of plant source P by pigs and allows diets containing reduced amounts of inorganic P to be nutritionally adequate. Based on previous reports (Veum et al., 2006; Veum and Ellersieck, 2008; Emiola et al., 2009), MCP was excluded from diets containing phytase unless the total P provided by the final diet (g of total P/kJ of NE) was not ≥100% of the available P presented by the reference diets.

For each general formulation scheme (simple and complex) 4 different ingredient choices were consid-

Table 1. Nonsolar energy use and resulting 100-yr global warming potential (GWP) associated with producing and delivering swine feed ingredients to feed mill and mixing formulated swine diets in Iowa[1]

Ingredient	Production energy, kJ/kg, as fed	100-yr GWP, g of CO_2 equivalents/kg, as fed
Ground corn[2]	24.0	4.3
Ground oats[2]	24.0	4.3
Full-fat roasted soybeans[2]	597.9	46.7
Soybean meal[3]	562.3	44.7
Soy oil[3]	1,817.8	143.9
DDGS[4]	4,700.0	86.4
Crude glycerol[5]	2,200.0	168.3
Ground limestone[6]	2,545.0	173.4
Salt[6]	1,635.0	279.8
Monocalcium phosphate[7]	13,800.0	1,104.4
Phytase[8]	40,000.0	2,000.0
L-Lysine	52,170.0	1,642.2
DL-Methionine[9]	88,000.0	5,557.2
Mixing and delivery of diet	10.5	1.2

[1] Values from Lammers (2009) unless otherwise noted.

[2] Values include energy and 100-yr GWP to deliver grain and soybeans to feed mill, roast soybeans, grind grain and soybeans, and move material within feed mill. Does not include energy use or 100-yr GWP associated with cultivation and storage of grain and oilseeds.

[3] Values include energy and 100-yr GWP associated with all steps of processing soybeans using commercial solvent extraction techniques. Values allocated between the 2 primary products of soybean processing based upon NE of final product mass (Lammers, 2009). Values do not include energy use or 100-yr GWP associated with production or storage of soybeans or production of solvent used in soybean processing.

[4] Values include energy and 100-yr GWP required to produce 3.3 kg of corn grain in the corn-soy sequence. Values exclude NE of 3.3 kg of corn grain not fed to pigs, the GE of 1.4 L of ethanol that is coproduced, and the potential displacement of other transportation fuels by ethanol. Values assume 0% capture of CO_2 produced by fermentation. DDGS = dried distillers grains with solubles.

[5] Values include energy and 100-yr GWP required to produce 14.2 kg of soy oil from the corn-soy sequence. Values exclude NE of 14.2 kg of soy oil not fed to pigs, the GE of 12.7 L of biodiesel that is coproduced, and the potential displacement of other transportation fuels by biodiesel.

[6] LaHore and Croke, 1978.

[7] Nielsen and Wenzel, 2007.

[8] Nielsen et al., 2007.

[9] Binder, 2003.

Table 2. Nutrient content of reference diets and estimated nutrient intake associated with production of one 136.0-kg market pig[1]

Diet	BW,[2] kg	Feed intake,[2] kg, as fed	NE, MJ/ kg, as fed	Standardized ileal digestible lysine, g/kg, as fed	Available P, g/kg, as fed
Phase 1	5–12	10.2	10.15	12.21	6.11
Phase 2	12–23	16.8	9.99	10.77	5.42
Phase 3	23–45	57.8	10.16	9.54	4.04
Phase 4	45–78	92.3	10.27	7.57	3.29
Phase 5	78–136	181.4	10.52	5.90	2.49
Gestation	157	37.0	10.72	4.29	5.06
Lactation	143	15.6	10.29	8.59	5.49
Total[3]		411.1	4.27	2.80	1.28

[1] Reference diets from Lammers et al. (2008) and Holden et al. (1996).

[2] BW and feed intake assumptions from Lammers (2009); includes death loss of 2.9 and 3.9% in nursery and grow-finish, respectively.

[3] Total kilograms of feed intake; gigajoules of NE; kilograms of standardized ileal digestible lysine; and kilograms of available P associated with production of one 136.0-kg market pig.

ered. The first (corn-SBM) represents what is a typical practice in the United States and consists primarily of corn and SBM. The second (oat-SBM) is a corn-SBM diet that includes oats. Diets for growing pigs were formulated to include 4% oats, and sow diets included up to 80% oats by mass for the oat-SBM strategy. These inclusion levels were selected based on Iowa State University recommendations (Holden et al., 1996) and crop production model results (Lammers, 2009). The third set of ingredients [oat-full-fat soybeans (**FFSB**)] is a corn-based diet that includes oats and replaces SBM with FFSB. An earlier study in Denmark reported replacing SBM with peas and rapeseed cake reduced nonsolar energy inputs for swine diet manufacture by 22% (Ericksson et al., 2005). The oat-FFSB diet strategy was designed to examine the efficacy of alternative sources of protein-feed ingredients. Full-fat soybeans were used as the primary source of AA, and SBM was removed from all diets. Diets for growing pigs and sows were allowed to include up to 10 and 80% oats, respectively, under the oat-FFSB diet scenario based on Iowa State University recommendations (Holden et al., 1996) and crop production model results (Lammers, 2009). The final ingredient set (coproducts) is a corn-SBM diet that includes maximal amounts of DDGS and crude glycerol. Diets for growing pigs were allowed to include up to 25% DDGS (DeDecker et al., 2006; Gibson and Karges, 2006; Lammers et al., 2009), and diets for sows included 35 to 40% DDGS (Honeyman et al., 2007). All diets within the coproducts formulation strategy included 10% crude glycerol (Kerr et al., 2007; Lammers et al., 2008, 2009). The combination of 25% DDGS and 10% crude glycerol has been shown to attenuate some of the pork quality issues associated with feeding increased amounts of DDGS (Lammers et al., 2009).

Ingredient choices and diet formulation strategies were then considered under the context of selected crop sequences. Our analysis did not compare every possible crop sequence × ingredient choice combination. Rather our analysis focused on combinations of most interest. The baseline combination is a corn-SBM diet and a corn-soy cropping sequence. This combination is representative of current Iowa practice. A slight modification of the baseline generated the second combination of the corn-soy-corn-oats sequence with an accompanying inclusion of oats in the diets fed to pigs. A third combination uses the corn-soy-corn-oats sequence and considers the potential of feeding oats and FFSB to pigs. Full-fat soybeans are not typically fed to pigs. However, there may be interest in increasing on-farm processing of feedstuffs, and roasting soybeans is a method of processing soybeans that can be done on-farm. The diet that includes full-fat soybeans is nested within the corn-soy-corn-oats sequence rather than the corn-soy sequence because producers most interested in on-farm roasting of soybeans are assumed to also be more interested in diversifying cropping sequences than others. The final combination is a corn-soy sequence that includes production of biofuels and feeding of biofuel coproducts. Coupled with simple and complex diet formulations, the 4 crop sequence × ingredient combinations create 8 crop sequence × diet formulation scenarios.

Ingredient lists from each formulation strategy were combined with nonsolar energy and 100-yr GWP values associated with processing feed ingredients and nonsolar energy and 100-yr GWP associated with cultivation of different crops in selected sequences. For each cropping sequence × diet formulation scenario, the nonsolar energy and 100-yr GWP required to grow, manufacture, and deliver adequate feed (approximately 4,300 MJ of NE, 2.8 kg of SID lysine, and 1.2 kg of available P) to produce one 136.0-kg market pig was determined.

Nonsolar Energy Inputs and Greenhouse Gas Emission

Three main types of nonsolar energy inputs were considered: diesel fuel, liquefied petroleum gas, and electricity. The energy used from these 3 inputs were calculated for each activity or process and then totaled. Emission of 3 greenhouse gases, CO_2, CH_4, and N_2O,

Table 3. Calculated nonsolar energy use and 100-yr global warming potential (GWP) associated with production of grains, oilseeds, and biomass from different cropping sequences in Iowa[1]

	Nonsolar energy use, kJ/kg, as fed		100-yr GWP, g of CO_2/kg, as fed	
Item	C–S[2]	C–S–C–O[2]	C–S[2]	C–S–C–O[2]
Corn grain	1,870.0	1,785.5	133.5	127.8
Corn stalks	53.4	53.4	4.3	4.3
Soybeans	1,893.4	1,878.7	140.8	139.5
Soybean meal[3]	1,349.1	1,338.6	100.3	99.4
Soybean oil[3]	4,789.2	4,752.1	356.1	352.8
Oat grain	NA[4]	2,888.4	NA	207.9
Oat straw	NA	238.6	NA	19.5

[1] Based on Lammers (2009).

[2] Sequence: C–S = corn, soybean; C–S–C–O = corn, soybean, corn, oat under seeded with leguminous cover crop.

[3] Assumes soybeans are processed into soybean meal (80% of soybean mass) with NE of 8.4 MJ/kg and 17% soybean oil (17% of soybean mass) with NE of 29.8 MJ/kg. A processing loss of 3% soybean mass is also assumed. Soybean cultivation energy allocated based on NE of final product mass (57% attributed to soybean meal, 43% attributed to soy oil). To generate 1.0 kg of soybean meal or soy oil, 1.25 or 5.9 kg of soybeans must be produced, respectively (Lammers, 2009).

[4] NA = not applicable.

were estimated based on fuel type (IPCC, 2006; EPA, 2008). Standardized 100-yr GWP for the 3 gases were used to calculate 100-yr GWP by energy type expressed in terms of CO_2 equivalents (IPCC, 2007). Diesel fuel is the most commonly used energy source for operating crop production equipment and transporting grain. To calculate the energy consumed as diesel fuel, an energy density of 38.46 MJ/L was assumed for diesel fuel (Downs and Hansen, 1998). For every gigajoule of diesel fuel combusted by agricultural equipment, an estimated emission of 82.73 kg of CO_2 equivalents occurs (IPCC, 2006, 2007). Liquefied petroleum gas is used as a major feedstock and source of energy in the manufacture of synthetic fertilizers and pesticides (Bhat et al., 1994). It is also commonly used to dry grain on-farm (Bern, 1998; Wilcke, 2004). It is estimated that 63.15 kg of CO_2 equivalents are released for every GJ of energy originating as liquefied petroleum gas (IPCC, 2006, 2007). Domestic electricity generation emission factors for Iowa (EPA, 2008) were used to estimate the 100-yr GWP resulting from use of electricity. It is estimated that 229.32-kg CO_2 equivalents are released for every GJ of electrical energy used (IPCC, 2007; EPA, 2008). Nonsolar energy use by fuel type and resulting 100-yr GWP were then totaled for each of the examined scenarios.

RESULTS AND DISCUSSION

The nonsolar energy and 100-yr GWP of individual crops for 2 cropping sequences in Iowa are summarized in Table 3. Production of corn grain requires the most energy per unit of land area but also produces the largest quantity of grain of any crop examined (Lammers, 2009). This results in corn requiring less nonsolar energy per kilogram of grain than soybeans and oats. Increasing the complexity of cropping sequences allows reduction in synthetic fertilizers applied to corn while maintaining or enhancing productivity. This results in corn grain grown in the corn-soy-corn-oats sequence requiring 5% less nonsolar energy compared with corn grain grown in the corn-soy sequence. A similar but less pronounced trend occurs in soybeans. As expected, the 100-yr GWP of individual crops within different crop sequences closely follows nonsolar energy use.

The calculated analysis of 4 formulation strategies without the use of synthetic AA and phytase (simple) is summarized in Table 4. The diet analysis presented is a weighted average of all feed associated with production of one 136.0-kg market pig. This includes 5 diets fed to growing pigs as well as the lactation and gestation feed required to produce one 136-kg market pig. Table 5 details the same formulation strategies but allows use of synthetic AA and the exogenous enzyme phytase (complex). As expected, the inclusion of L-lysine reduces CP intake per megajoule of NE. Intake of CP content from diets containing L-lysine is 83 to 91% of the CP intake from the simple diet formulations. Including the exogenous enzyme phytase consistently enables reduction of total P in diet formulations. The benefits of phytase are less pronounced when formulating diets with ≥25% DDGS. This is because DDGS has sufficient available P to exclude most MCP from the simple diet formulation. The advantage of including phytase is the ability to reduce the amount of MCP and other inorganic sources of P in the diet. Because the simple coproducts diet formulation already has <1% MCP, adding phytase does not reduce MCP inclusion as much as in other diet formulation.

Eight crop sequence × diet formulation scenarios are presented in Table 6. Inclusion of L-lysine and exogenous phytase is typical of conventional pig production in the United States. The complex formulation strategy incorporates this practice. The complex formulation strategy requires less nonsolar energy input per mega-

Table 4. Composition and calculated analysis for 4 simple diet formulations (as-fed basis) required for production of one 136.0-kg market pig[1]

	Formulation strategy			
Item	Corn-SBM	Oat-SBM	Oat-FFSB	Coproduct
Ingredient				
Corn,%	76.84	63.12	45.64	44.04
SBM, %	19.85	18.03	0	15.89
Oats, %	0	15.57	20.93	0
FFSB, %	0	0	29.66	0
DDGS, %	0	0	0	26.88
Crude glycerol, %	0	0	0	10.00
Ground limestone, %	2.02	2.14	2.57	2.98
Salt, %	0.29	0.22	0.28	0
Monocalcium phosphate, %	1.00	0.92	0.92	0.21
Total	100.00	100.00	100.00	100.00
Estimated feed intake, kg	417.35	435.31	425.25	465.73
Analysis				
NE, MJ/kg	10.24	9.81	10.05	9.17
SID Lysine:NE, g/MJ	0.66	0.66	0.66	0.66
Available P:NE, g/MJ	0.30	0.30	0.30	0.31
CP:NE, g/MJ	15.24	15.44	16.11	19.26
Total P:NE, g/MJ	0.54	0.55	0.55	0.53

[1] Includes 5 phase diets for wean-to-market pigs, 1 lactating sow diet, and 1 gestating sow diet. All diets within a phase formulated to have equal ratios of standardized ileal digestible (SID) lysine to NE and available P to NE. No synthetic AA or exogenous enzymes included. SBM = soybean meal; FFSB = full-fat soybeans; DDGS = dried distillers grains with solubles.

joule of NE delivered to pigs for all crop sequence × ingredient combinations. The complex formulation strategy reduces nonsolar energy input per megajoule of NE by 4 to 5% for all diets except the coproduct diet. The simple formulation of the coproduct diet requires less than 1% more nonsolar energy input than the complex formulation of the coproduct diet. As expected, 100-yr GWP follows input energy. Including phytase and L-lysine reduces 100-yr GWP associated with pig diet production by 2 to 7% depending on ingredient choice.

Table 5. Composition and calculated analysis for complex[1] diet formulations (as-fed basis) required for production of one 136.0-kg market pig

	Formulation strategy			
Item	Corn-SBM	Oat-SBM	Oat-FFSB	Coproduct
Ingredient				
Corn,%	83.17	68.04	52.34	51.99
SBM, %	14.91	14.16	0	8.98
Oats, %	0	15.88	21.15	0
FFSB, %	0	0	24.34	0
DDGS, %	0	0	0	26.66
Crude glycerol, %	0	0	0	10.00
Ground limestone, %	1.49	1.53	1.75	2.12
Salt	0.22	0.24	0.30	
Monocalcium phosphate, %	0.03	0	0	0
L-Lysine, %	0.17	0.14	0.11	0.24
Exogenous phytase,[2] %	0.01	0.01	0.01	0.01
Total	100.00	100.0	100.0	100.0
Estimated feed intake, kg	405.19	423.83	417.01	450.31
Analysis				
NE, MJ/kg	10.54	10.08	10.24	9.49
SID Lysine:NE, g/MJ	0.66	0.66	0.66	0.66
Available P:NE, g/MJ	0.30	0.30	0.30	0.30
CP:NE, g/MJ	13.22	13.77	14.64	16.06
Total P:NE, g/MJ	0.32	0.31	0.32	0.44

[1] Includes 5 phase diets for wean-to-market pigs, 1 lactating sow diet, and 1 gestating sow diet. All diets formulated to have adequate threonine, tryptophan, and methionine. Synthetic lysine added as needed to meet requirements. SBM = soybean meal; FFSB = full-fat soybeans; DDGS = dried distillers grains with solubles; SID = standardized ileal digestible.

[2] Exogenous phytase assumed to have phytase activity of 5,000 U/g of material.

Table 6. Nonsolar energy use and 100-yr global warming potential (GWP) associated with feeding one 136.0-kg market pig from select crop sequence × diet formulation strategies

	C–S[1]		C–S–C–O[1]		C–S–C–O[1]		C–S[1]	
	Corn-SBM[2]		Oat-SBM[2]		Oat-FFSB[2]		Coproduct[2]	
Item	Simple[3]	Complex[3]	Simple[3]	Complex[3]	Simple[3]	Complex[3]	Simple[3]	Complex[3]
Corn, kJ/MJ of NE	142.1	149.5	116.4	122.1	82.2	92.5	91.0	103.8
Oats, kJ/MJ of NE	0	0	46.2	45.9	60.7	60.2	0	0
Soybean meal, kJ/MJ of NE	37.1	27.0	34.9	26.7	0	0	33.1	18.1
Full-fat soybeans, kJ/MJ of NE	0	0	0	0	73.1	58.9	0	0
DDGS,[4] kJ/MJ of NE	0	0	0	0	0	0	137.8	132.0
Crude glycerol, kJ/MJ of NE	0	0	0	0	0	0	24.0	23.2
Limestone, kJ/MJ of NE	5.0	3.6	5.6	3.9	6.5	4.3	8.3	5.7
Salt, kJ/MJ of NE	0.5	0.3	0.4	0.4	0.5	0.5	0	0
Monocalcium phosphate, kJ/MJ of NE	13.5	0.4	12.9	0	12.6	0	3.2	0
L-Lysine, kJ/MJ of NE	0	8.4	0	7.2	0	5.6	0	13.2
Phytase, kJ/MJ of NE	0	0.4	0	0.4	0	0.4	0	0.4
Mix and deliver, kJ/MJ of NE	1.0	1.0	1.1	1.0	1.0	1.0	1.1	1.1
Total input energy, kJ/MJ of NE	199.2	190.6	217.5	207.6	236.6	223.4	298.5	297.5
Total 100-yr GWP, g of CO_2/MJ of NE	14.8	13.7	16.1	15.0	17.6	16.3	14.4	14.1

[1] Crop sequence: C–S = corn, soybean; C–S–C–O = corn, soybean, corn, oat under seeded with leguminous cover crop.

[2] Ingredient choice: corn-SBM = typical corn, soybean meal diet; oat-SBM = includes <16% oat; oat-FFSB = full-fat soybeans as primary source of AA; coproduct = maximal amounts of biofuel coproducts.

[3] Formulation strategy: simple = no synthetic AA or exogenous phytase; complex = includes synthetic AA and exogenous phytase.

[4] DDGS = dried distillers grains with solubles.

The complex corn-SBM diet requires less nonsolar energy input per megajoule of NE delivered to pigs than the simple formulation. Adding L-lysine to a corn-SBM diet allows removal of approximately 25% of the SBM in the diet. This results in a reduction of energy needed to produce soybeans and process SBM, but an increase in energy to produce L-lysine. Removing some SBM and adding L-lysine was energetically favorable in all cases. The simple formulation of the corn-SBM, oat-SBM, and coproduct diets requires 3 to 5% more nonsolar energy to deliver adequate lysine as SBM compared with the complex formulations that combine SBM and L-lysine.

Replacing some FFSB with L-lysine was also energetically favorable. Adding L-lysine to the simple oat-FFSB diet allowed removal of nearly 20% of the FFSB originally used. This results in a reduction of energy needed to produce and process soybeans, but an increase in energy to produce L-lysine. The simple formulation of oat-FFSB requires 13% more nonsolar energy to deliver adequate lysine as FFSB compared with the complex formulation that combines FFSB and L-lysine.

In addition to being energetically advantageous under the examined scenarios, adding L-lysine to the diet allows dramatic reduction in the total CP delivered to the animal. This in turn reduces the potential for N excretion by pigs into the environment. Increasing pork production per unit of feed N delivered to pigs has been a goal of United States pork producers, which is supported by the inclusion of L-lysine.

Feeding phytase allows nearly complete removal of MCP from pig diets. Inclusion of phytase in pig diets enables diets with less total P to be nutritionally adequate and may reduce P excretion by pigs (Veum et al., 2006; Veum and Ellersieck, 2008; Emiola et al., 2009). Because MCP requires a large amount of nonsolar energy to produce, its near elimination from diet formulations greatly reduces nonsolar energy inputs for complete diet production. Phytase also requires a large amount of nonsolar energy to produce, but the benefits of phytase can be achieved by including very small amounts of the exogenous enzyme in the diet. The additional energetic cost of including phytase is more than offset by reductions in the nonsolar energy input required if providing adequate available P as MCP. Because feeding exogenous phytase enables the pig to utilize some of the previously unavailable P found in corn and SBM, P excretion may also be reduced.

Regardless of formulation strategy, a corn-SBM diet required the least nonsolar energy input per megajoule of NE delivered to the pig. The optimal approach to reducing energy use and reducing 100-yr GWP was the complex corn-SBM diet produced under a corn-soy cropping sequence. The oat-SBM diet type required 9% more nonsolar energy input per megajoule of NE than the corn-SBM diet type for both formulation strategies. This is likely due to the energetic cost of oat cultivation relative to corn production. Producing 1.0 kg of oats is estimated to require 62% more energy than cultivating 1.0 kg of corn grain. Although corn requires the most energy input per square meter of cropland, it also yields the most grain per square meter of cropland (Lammers 2009). Cultivating oats requires less energy per square meter of cropland but also yields much less grain per square meter (Lammers 2009).

The oat-FFSB diet type is not energetically favorable compared with the corn-SBM and oat-SBM approaches. Roasting soybeans requires large inputs of nonsolar energy and does not deliver proportional benefits in terms of total nonsolar energy input per megajoule of NE delivered to pigs. Previous European examinations of pig production have suggested that avoidance of SBM in pig diets is energetically and environmentally beneficial (Ericksson et al., 2005). Our results disagree with those conclusions. Soybean meal used in the Danish study was imported from South America (Ericksson et al., 2005), but our study assumed soybean processing occurs near the site of pig production within Iowa (Lammers, 2009). Imported SBM is a major source of AA for European swine diets (Ericksson et al., 2005; Dalgaard et al., 2008). Given the leadership of Iowa in soybean production (USDA, 2009) and processing (Hardy, 2009) in the United States, some of the previously reported advantages of displacing SBM with alternative protein sources (Ericksson et al., 2005) do not apply directly in Iowa or other major soybean production and processing regions where pigs are fed.

Diets containing ≥25% DDGS and 10% crude glycerol required more nonsolar energy input per megajoule of NE than any other diet scenario. The production energy of coproduct feeds is larger than the nonsolar energy needed to grow and process other major feed ingredients. For example, if we assume a corn-soy sequence, 1.0 kg of ground corn requires 1,870 kJ to cultivate and harvest and 24.0 to grind and deliver or 1,894 kJ of total nonsolar energy input per kg. Similarly, 1.0 kg of SBM produced from a corn-soy sequence requires 1,349.1 kJ to cultivate and harvest and 562.3 kJ to process or 1,911.4 kJ of total nonsolar energy input per kg. Alternatively, DDGS requires 4,700 kJ per kg, and crude glycerol requires 2,200 kJ per kg. The NE of the 4 ingredients is also different, 11.1, 8.4, 7.0, and 9.9 MJ/kg, for corn grain, SBM, DDGS, and crude glycerol, respectively. Thus, each megajoule of NE from corn grain and SBM requires 171 and 228 kJ of nonsolar energy, respectively, whereas each megajoule of NE from DDGS and crude glycerol require 671 and 222 kJ of nonsolar energy, respectively. If return of NE for pigs per kilojoule of nonsolar energy input is the only concern, feeding biofuel coproducts is not favorable. However, if the decision has already been made to produce biofuel, feed coproducts will be cogenerated. Including those existing coproducts in swine diets may be economical for individual swine producers.

The complex coproduct diet required only 1% less nonsolar energy per megajoule of NE than the simple formulation compared with reductions of 4 to 5% for other diet types because of the nature of DDGS. Fermentation of corn grain causes the corn-based P to be more available to pigs in DDGS than P in corn. Because P present in DDGS is more available to the pig, less MCP is needed in the simple diet formulation of the coproduct diet type. The main energetic advantage of the complex diet formulation for the other diet types was removal of ≥12.2 kJ of nonsolar energy input per megajoule of NE associated with providing available P as MCP. With less MCP to remove in the simple coproduct diet, the energetic benefit achieved by adding phytase and removing MCP was reduced.

Conclusions

Including DDGS and crude glycerol requires more nonsolar energy than simply feeding corn grain and SBM, but for swine producers near biofuel production plants, adding biofuel coproducts may be economical. Adding phytase to diets and reducing or removing MCP reduces the nonsolar energy cost of swine feed and P excretion from the pig. Because most agricultural soils in Iowa have adequate amounts of P for crop production, this is a double benefit of phytase. The energetic and environmental effects of feeding L-lysine are less clear. Adding L-lysine reduces the CP content of diets and meets the SID lysine needs of pigs with less total nonsolar energy input. Reducing the CP content of swine diets reduces excretion of N by pigs and ultimately the N concentration of manure delivered to crop fields. Although reducing N excretion by livestock has been a focus of environmental management strategies, this benefit might be achieved at the cost of requiring more nonsolar energy use for manufacturing synthetic fertilizers necessary for crop production. Crop producers take into account crop nutrients delivered by manure when determining how much synthetic fertilizer to apply. If less manure-based N is delivered to cropland, then more synthetic N will typically be applied. The current study does not consider crop nutrient value of pig manure under different diet types or formulation strategies. Further examination of the interactions among nonsolar energy use for synthetic fertilizers and different strategies to deliver adequate AA to pigs is warranted and should be a priority in considering the nonsolar energy use and environmental impacts of pig production systems.

The current study is not a complete life cycle assessment of pig production in Iowa. However, the presented inventory of nonsolar energy and 100-yr GWP associated with growing and processing swine feed ingredients provides essential information for life cycle assessment of pig production. Results from this project can be combined with other studies to more fully understand the nonsolar energy use and 100-yr GWP of Iowa swine production.

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