MAXIMIZING NET INCOME FOR PORK PRODUCERS BY DETERMINING THE INTERACTION BETWEEN DIETARY ENERGY CONCENTRATION AND STOCKING DENSITY ON FINISHING PIG PERFORMANCE, WELFARE, AND CARCASS COMPOSITION

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By

Garrett N. Rozeboom

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Abstract

Marketplace volatility in the pork industry demands that producers re-evaluate production practices in order to remain profitable. Stocking density and dietary energy concentration independently affect performance and economic returns of growing finishing pigs. However, there is limited information on whether the interaction between these two factors is important for optimizing productivity and maximizing economic returns. The objective of this study was to determine if the dietary energy concentration that maximizes performance and economic returns varies with stocking density. Treatments were arranged as a 2 × 3 × 3 factorial included; sex (barrows and gilts), dietary energy (2.15, 2.30 and 2.45 Mcal NE/kg) and stocking density (14, 17 or 20 pigs per pen providing 0.92, 0.76 and 0.65 m^2 per pig, respectively). A total of 932 pigs were used with three replications of 18 treatments. Pigs were randomly assigned to pens within sex to achieve an average initial BW of 75 kg. Wheat and barley based diets were formulated to meet or exceed the pigs' nutrient requirements (National Research Council, 2012) and were fed in three phases within sex at each energy concentration. Overall (75 to 118 kg BW), as dietary energy increased from 2.15 to 2.45 Mcal NE/kg, ADG increased from 1.17 to 1.23 kg/d, ADFI decreased from 4.09 to 3.77 kg/d, G:F improved from 0.29 to 0.33 and caloric intake increased from 8.81 to 9.29 Mcal NE/d ($P < 0.05$). When stocking density was increased from 14 to 20 pigs per pen, ADG (1.21 to 1.17 kg/d), ADFI (4.00 to 3.82 kg/d) and caloric intake (9.19 to 8.12 Mcal NE/d) decreased ($P < 0.05$). Neither dietary energy concentration nor stocking density had a significant effect on the utilization of calories for growth (Gain:Mcal). Feeder visits per pig and time at the feeder per pig were decreased when stocking density increased from 14 to 20 pigs per pen ($P < 0.01$). Total time at the feeder and time at the feeder per pig were increased when dietary energy decreased from 2.45 to 2.15 Mcal of NE/kg. Per pen, aggressive incidents at the feeder increased ($P < 0.05$) and there was a tendency for increased aggressive incidents per pig ($P = 0.09$) when stocking density was increased. There was a linear increase ($P < 0.01$) in income over feed cost (IOFC) with increased stocking density, and there was a tendency ($P = 0.08$) for a linear increase in IOFC when dietary energy was increased. The dietary energy which maximized the IOFC did not vary with stocking density. Dietary energy and stocking density independently affect pig performance, behavior, and economic returns and the optimal dietary energy does not depend on stocking density (dietary energy by stocking density interaction).

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I would like to give my sincere gratitude to my friends and family, as without their support and encouragement, I would not have completed my studies. They have been there at my lowest point to pick me up and I know I can always count on them.

Dedication

I would like to dedicate this thesis to my parents, Dale and Cheryl Rozeboom. Their prayers and encouragement carried me through my studies. My father's professional knowledge was helpful but his encouragement and understanding kept me focused and driven. My mother was the stronghold I depended on when I was broken and she was faithful when I felt faithless. Their love, support and faith have made me into the man I am today.

"Trust in the lord with all your heart and do not lean on your own understanding. In all your ways acknowledge him and he will make your path straight"

Proverbs 3:5-6

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List of Abbreviations

°C	degrees Celsius
A	area
AA	amino acids
ADF	acid detergent fiber
ADFI	average daily feed intake
ADG	average daily gain
AIA	acid insoluble ash
ATP	adenosine triphosphate
Avg	average
BMR	basal metabolic rate
BW	body weight
CDN	Canadian currency
CP	crude protein
CV	coefficient of variation
d	days
EE	ether extract
FHP	fasting heat production
FI	feed intake
Fig	figure
FREQ	frequency
FTU	phytase units
g	gram
g	gravity
G:F	gain to feed ratio
GE	gross energy
GIT	gastrointestinal tract
h	hour
HCW	hot carcass weight
HI	heat increment
HP	heat produced
IOFC	income over feed cost
IU	international units
k	space allowance coefficient
kcal	kilocalories
kg	kilogram
LD	lipid deposition
m	meter
Mcal	megacalorie
ME	metabolizable energy
MIXED	mixed model
mm	millimeter
MRKT	market
NE	net energy
NE_m	net energy maintenance
NE_p	net energy production
P	probability value
PD	protein deposition
PD_{max}	maximum protein deposition
PIC	Pig Improvement Company
ppm	parts per million
PROC	procedure
RPM	rotations per minute
s	second
SAS	Statistical Analysis Software
SEM	standard error of the mean
SID	standardardized ileal digestibility
wt	weight

1. Literature review

1.1. Introduction

Marketplace volatility in the pork industry demands that producers regularly re-evaluate production practices in order to remain profitable, increase profits, or minimize losses. Feed costs and barn throughput are among the most important production factors optimized to ensure economic returns are maximized. Increased incorporation of low cost ingredients into the diet will reduce feed costs, but typically also means that the dietary energy content of the diet is reduced. Barn throughput can be adjusted based on the availability of pigs. When feeder pig prices decrease or the number of piglets born exceeds barn capacity, producers may want to increase the stocking density.

From 2003 to 2013, the cost of feed rapidly increased due to greater global demand for grains (Patience, 2013). Increased feed costs were the primary cause for the overall increase in the cost of pork production (Taheripour et al., 2013). In 2013, feed costs represented 65% of the total cost of pork production (Young, personal communication). Finishing pigs (60 kg BW to slaughter) consume more than 60% of the total feed required for a pig to reach market weight (Patience et al., 2002). Furthermore, dietary energy is the most expensive component of the ration and the increased global demand for grains has resulted in a 4 fold increase in the cost of energy from basal ingredients in the past 8 yr (2005 to 2013; Patience, 2013). Feed efficiency (G:F) can usually be improved by increasing dietary energy, but this does not always result in increased returns (Beaulieu et al., 2009). The dietary energy concentration that maximizes the income over feed costs (IOFC) depends on optimum growth and G:F. However, the optimum growth rate and G:F may not be the fastest or most efficient.

Barn throughput is the number of pigs produced in a barn within a specific time. Increasing the barn throughput allows the producer to increase gross revenue generated from pigs sent to the slaughter facility. Increasing the number of pigs finished in a year spreads fixed costs across more pigs. Barn throughput can be manipulated by adjusting market weight or stocking density or both.

Stocking density refers to the number of pigs per pen. Increasing stocking density is the most common way of increasing the barn throughput in commercial finishing operations. As stocking density is increased, the space allowance per pig is decreased which may cause crowding, especially prior to market. Crowding pigs can reduce growth rate and decrease animal welfare by increasing the prevalence of injury, stess, and mortality (Anil et al., 2007). A severe reduction in growth could decrease barn throughput. However, in most instances, the increase in stocking density will compensate for the negative effects on growth, and overall barn throughput will increase (Anil et al., 2007).

Extensive research has demonstrated the importance of both dietary energy and stocking density for maximizing economic returns in pork production. However, work examining the interaction of these two variables is lacking. An interaction would imply that the correct dietary energy will depend on the stocking density and the best combination will result in optimal production and maximum net returns. Moreover, the combination which is optimal for growth may be different than the combination which maximizes net returns.

1.2. Dietary energy

Energy is the capacity or the power to do work (Houghton Mifflin Company, 2012). There are many forms of energy but, in nutrition, energy is defined as the amount of chemical energy contained within a foodstuff which is released as a result of oxidation of the organic compounds (National Research Council, 2012). Dietary energy is not classified as a nutrient, but results from the oxidation of carbohydrates, lipids, and proteins (Patience et al., 1995). The first law of thermodynamics states that energy cannot be created or destroyed, but can only be transferred from one form to another. In nutrition, dietary energy is transferred via ATP to perform metabolic functions, stored as chemical energy, or lost as feces, urine, or as gaseous losses (Rijnen et al., 2004). An adequate supply of dietary energy allows pigs to perform maintenance and productive functions (Kil et al., 2013). However, if dietary energy is inadequate, animals will derive energy from the catabolism of tissues (Reese et al., 1982).

In North America, the most common system used to evaluate the dietary energy provided to pigs is the energetic loss system. Four measurements are used to describe energy utilization:

gross energy (GE), digestible energy (DE), metabolizable energy (ME), and net energy (NE; Fig. 1.1). Each measurement accounts for different energetic losses.

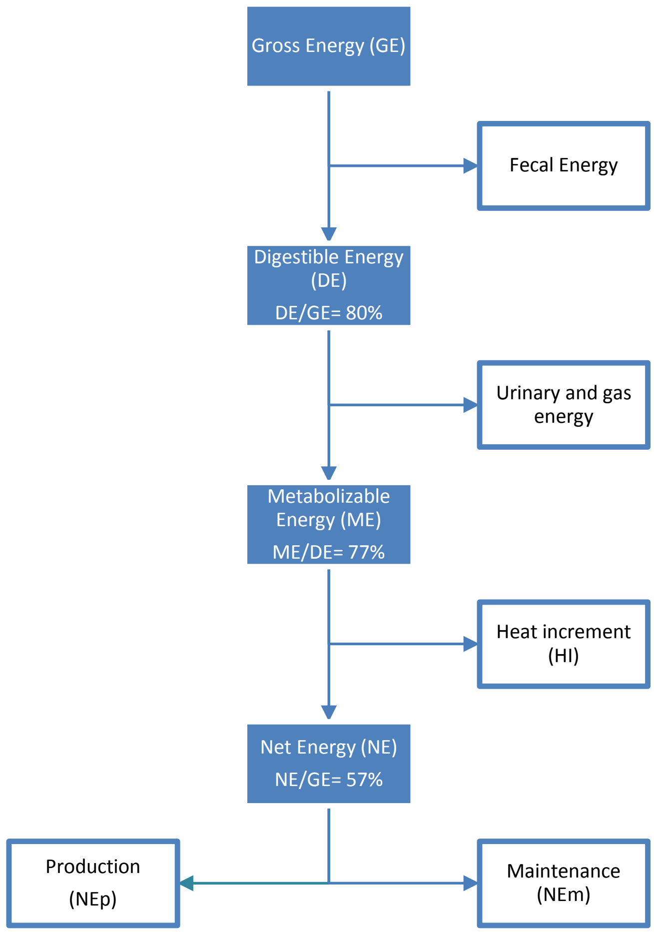

Figure 1.1. Partitioning of energy in swine nutrition with efficiency approximations (adapted from Noblet et al., 2004)

Gross energy is the amount of energy released upon complete oxidation of the feedstuff and is determined by calorimetry (National Research Council, 2012). Based on calorimetry, nutrient GE values have been established with carbohydrates providing a range of 3.7 kcal/g (glucose and simple sugars) to 4.2 kcal/g (starch and cellulose), proteins providing 5.6 kcal/g and lipids providing 9.4 kcal/g (National Research Council, 2012). These values can be used to estimate the GE of a given feedstuff or diet. Gross energy represents the total amount of energy which is potentially available to the pig.

Digestible energy represents the portion of GE that is not excreted in the feces (Eq. 1.1). Energy that is not excreted in the feces is assumed to be absorbed by the pig (De Lange and Birkett, 2005). Digestible energy is calculated by subtracting the GE excreted in feces from the GE of the feed. The efficiency of DE/GE for ingredients can range from 0 to 100% and for diets from 70 to 90% (Noblet and van Milgen, 2004).

$$\boldsymbol{DE = GE - Energy_{Feces}} \tag{1.1}$$

Metabolizable energy represents the amount of energy available for utilization by the pig (Kil et al., 2013). It is calculated by subtracting the energy lost in urine and gas from the DE (Eq. 1.2). In pigs, the gaseous losses are minimal (i.e., 0.4% of DE) and are often ignored when estimating ME (Noblet et al., 1994). Urinary energy is highly dependent on the amount of crude protein (CP) in the diet. As the CP content of the diet increases, the ME:DE ratio decreases. The ME:DE ratio of diets for growing pigs is typically 0.96 (Noblet, 2000).

$$\boldsymbol{ME = DE - (Energy_{urine} + Energy_{gas})} \tag{1.2}$$

The North American swine industry has commonly used the ME or DE systems to estimate dietary energy utilization. However, these systems do not measure the energetic cost of work associated with mastication, digestion, absorption, and metabolism of feed (Brody, 1945). These processes comprise the heat increment (HI). Without accounting for the energetic cost of HI, a “true” estimation of energy used for maintenance and production cannot be made.

Net energy is the only measurement that accounts for the energetic losses of the HI. Net energy is defined as ME minus the HI (Eq. 1.3). Subtracting the HI from ME estimates the NE available for production (NE_p) and maintenance functions (NE_m). Energy used for production can be divided into energy for growth, gestation, lactation, and movement. Approximately one-third of the energy utilized by the pig is required for maintenance and the remaining two-thirds is available for productive functions (Black and De Lange, 1995). However, the energy used for maintenance will fluctuate, depending on the stage of growth, genetics, environment, and nutrition of the pig (Kil et al., 2013).

$$\boldsymbol{NE = ME - HI} \qquad 1.3$$

Net energy used for maintenance can be estimated using the basal metabolic rate (BMR). Basal metabolic rate represents the amount of energy required for the pig to perform vital functions. Fasting heat production (FHP) can be used to predict BMR (Birkett and De Lange, 2001). Fasting heat production is the measurement of heat produced (HP) during a fasting state. However, FHP does not accurately predict the true NE used for maintenance because it measures both the energy required for basal body functions and the HP from the generation of ATP from nutrient stores (van Milgen and Noblet, 2003). In a fasting state, pigs will catabolize body tissues to provide energy for vital processes. The catabolism of tissues increases HP, and FHP includes the HP produced by tissue synthesis. To accurately predict the maintenance energy, BMR should only account for the energy required for maintenance and the energy required to catabolize tissue. To adjust for the HP from ATP generation from body tissues, the BMR is multiplied by the efficiency of deriving ATP from retained energy, which allows for a more accurate prediction of FHP (De Lange and Birkett, 2005).

Although it is more difficult to obtain NE values, it is commonly agreed upon that NE properly characterizes the dietary energy content of an ingredient or ration (Noblet and van Milgen, 2004). There are 3 methods commonly used to estimate the NE of a feedstuff: comparative slaughter technique, indirect calorimetry, and regression equations developed from indirect calorimetry and the nutrient content of a feedstuff (Noblet et al., 1994).

The comparative slaughter technique measures the amount of retained energy or energy gained by the carcass (Ayoade et al., 2012). Retained energy is obtained simply by determining the amount of energy that is retained within the carcass. These measurements are taken at the beginning and end of an experiment. This allows for the calculation of energy retained during a defined period of time. Retained energy represents the proportion of energy used for NE_p. Along with the carcass energy, a predicted value for FHP must be used to estimate NE_m for the trial (Eq. 1.4; Ayoade et al., 2012)

$$\boldsymbol{NE = RE + NE_m} \tag{1.4}$$

Indirect calorimetry requires a measurement of the respiration of CO_2 and O_2. Pigs are placed in chambers and measurements of O_2 consumption and the production of CO_2, CH_4, and N are obtained to allow for the calculations of HP (Eq. 1.5; Brouwer, 1965).

$$\boldsymbol{HP = (3.866 \times O_2 consumption) + (1.200 \times CO_2\ production) - (0.518 \times CH_4\ production) - (1.431 \times N\ production)} \tag{1.5}$$

This calculated value is an exact value for energy produced based on the gaseous exchange. Carbon dioxide (CO_2) is a product of ATP generation thus, the measurement of CO_2 can be used to determine the amount of energy produced from a diet.

Estimation equations for NE [eq.1.6 (Noblet et al., 1994)] are based on energy values that were obtained from calorimetry studies. Most of the equations were established in Europe and adapted for North American diets. The following is an example of a regression equation used to estimate NE:

$$\boldsymbol{NE = (0.726\ x\ ME) + (1.33\ x\ EE) + (0.39\ x\ starch) - (0.62\ x\ CP) - (0.83\ x\ ADF)} \tag{1.6}$$

The efficiency of utilization of ME for NE is 60% for crude protein and crude fiber, 90% for fat, and 82% for starch (Noblet and Van Milgen, 2004). Metabolizable energy and DE measurements overestimate the energy content of fiber and protein and underestimate the energy value of oils, fats, and starch (Noblet, 2007). The NE system allows for a more accurate prediction of dietary energy by accounting for the difference in the utilization of ME among nutrients.

1.2.1. Effect of dietary energy on feed intake

The effects of dietary energy concentration on feed intake (FI), growth, and G:F have been well researched and are discussed below. Table 1.1 displays FI, growth, G:F and caloric intake from experiments which evaluated the effects of dietary energy concentration on animal growth performance and G:F.

Pigs tend to eat to meet their requirements for energy and, therefore, FI is affected by the energy concentration of the diet (National Research Council, 2012). Varying dietary energy concentration requires that pigs attempt to adjust FI to maintain a constant or nearly constant caloric intake (Quiniou and Noblet, 2012). However, if the dietary energy is very low, then FI cannot compensate sufficiently to maintain a constant caloric intake and caloric intake will decrease (Fig. 1.2). The gut capacity of the pig will limit its ability to consume enough feed to meet its caloric requirement for maximum growth (Whittemore, 1993; Nyachoti et al., 2004). Whittemore et al. (1993) wrote that the limits of gut capacity are most apparent in young pigs (less than 20 kg), and thus energy-dense diets should be fed to young animals.

Beaulieu et al. (2009) showed that when DE decreased from 3.57 to 3.09 Mcal/kg, there was a linear increase in average daily feed intake (ADFI) from 2.44 to 2.66 kg in growing-finishing pigs (31 to 115 kg BW). However, pigs receiving the 3.57 Mcal/kg treatment consumed 8.71 Mcal of DE/d whereas the pigs on the 3.09 treatment consumed only 8.22 Mcal of DE/d. As dietary energy decreased, there was a linear decrease in daily caloric intake. Total daily caloric intake was restricted by the animal's ability to consume enough feed when the less energy dense diet was fed. Similar results have been reported by Quiniou and Noblet (2012). In a second trial conducted by Beaulieu et al. (2009), pigs (37 to 118 kg BW) fed a diet containing 3.12 Mcal of DE/kg were able to increase FI to the point where caloric intake was not different from pigs fed a diet containing 3.43 Mcal of DE/kg. Similar to this, Smith et al. (1999) and De La Llata et al. (2001a) reported that growing-finishing pigs (36 to 120 kg and 45 to 105 kg BW, respectively) compensated completely for reduced dietary energy (from 3.61 to 3.34 and 3.57 to 3.31 Mcal of ME/kg, respectively) by increasing FI, so that the intake of ME did not differ among dietary energy treatments.

Not all experiments have shown a difference in FI due to changes in dietary energy concentrations. Kil et al. (2011) reported that when dietary energy was increased from 2.13 to 2.37 Mcal of NE/kg there was no difference in FI, but there was a tendency for total caloric intake to increase as dietary energy increased. Apple et al. (2004) also reported that the variation in dietary energy concentration did not affect FI in pigs growing from 84 to105 kg BW.

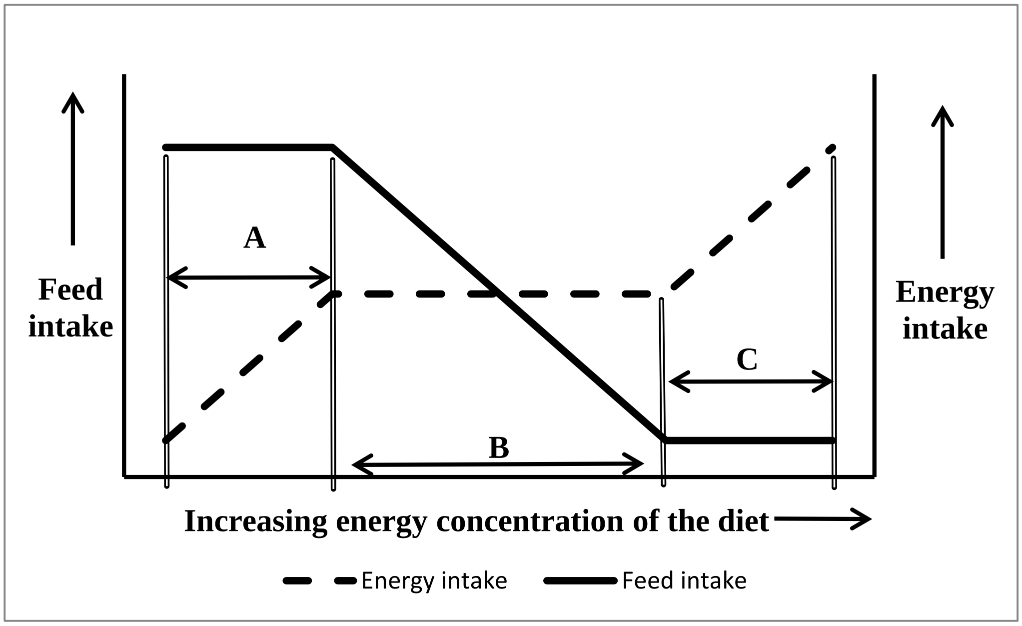

Figure 1.2. Schematic diagram of the relationship between feed and energy intake and the energy concentration of the diet. The “A” gap represents the limitations of gut capacity. In the “B” gap, energy requirements are met and FI is adjusted as energy concentration is increased. In the “C” gap energy intake exceeds energetic needs and the animal can no longer decrease FI (minimum gut fill) (adapted from Cole et al., 1972)

Table 1.1. Summary of results from studies that investigated the effect of dietary energy concentration on growing-finishing pig performance

	Mcal of ME/kg		ADG		ADFI		G:F		Caloric intake, Mcal/d	
	Low	High	Low	High	Low	High	Low	High	Low	High
Smith et al. (1999) 44.5 to 104.3 kg, BW	3.31	3.57	0.92	0.91	2.80[a]	2.56[b]	0.33[a]	0.36[b]	9.29	9.12
De La Llata et al. (2001a) 36 to 120 kg, BW	3.34	3.61	0.74[a]	0.78[b]	2.20	2.07	0.34[a]	0.38[b]	7.35	7.47
Apple et al.[1] (2004) 87 to 105 kg, BW	3.30	3.48	0.64	0.68	2.15	2.08	0.30[a]	0.33[b]	7.10	7.24
Weber et al.[1] (2006) 86 to 112 kg, BW	3.35	3.58	0.95	0.98	2.58[a]	2.45[b]	0.37[a]	0.42[b]	8.64	8.79
Beaulieu et al.[2,3,4] (2009) 31 to 115 kg, BW	2.97	3.43	1.00[a]	1.03[b]	2.66[a]	2.44[b]	0.39[a]	0.42[b]	7.90[a]	8.36[b]
Hinson et al.[5] (2011) 100 to 123 kg, BW	3.32	3.54	0.98[a]	1.23[b]	3.00	3.23	0.32[a]	0.39[b]	9.95[a]	11.42[b]
Kil et al.[6] (2011) 84 to 130 kg BW	3.31	3.82	1.21[a]	1.43[b]	3.70	3.86	0.33[a]	0.38[b]	7.92	9.06
Quiniou and Noblet[7,8](2012) 36 to 109 kg, BW	2.63	3.47	1.05[a]	1.16[b]	3.22[a]	2.68[b]	0.33[a]	0.43[b]	8.46[a]	9.31[b]

[ab] Within a performance measure and experiment, means without a common superscript differ ($P < 0.05$).
[1] Actual ME intake not reported, values reported are = ADFI × Mcal of ME/kg
[2] Data reported from trial 1 of the experiment
[3] Diets formulated using digestible energy (DE) values were converted using the following equation ME= DE × .96
[4] *P*-values for caloric intake based on Mcal of DE/d
[5] Tendency for ADFI to increase when dietary energy was increased ($P < 0.10$)
[6] Tendency for caloric intake to increase when dietary energy was increased ($P < 0.10$)
[7] Energy values were reported using MJ/kg and were converted to Mcal/kg= MJ × 0.239
[8] *P*-values for caloric intake based on MJ of NE/d

1.2.2. Effect of dietary energy on growth

Pig growth depends on the quality and quantity of ingredients supplied from the diet, including energy. A sufficient intake of nutrients and energy is greatly dependent on the animal's ability to consume enough feed. There is a general agreement that energy is the first limiting factor in determining lean growth (van Milgen et al., 2001). As stated previously, pigs will compensate for reduced dietary energy concentration by consuming more feed in order to meet their energetic requirements for growth. Furthermore, a pig will reduce FI when energy concentration is increased. Pigs will tend to stop eating or decrease intake when caloric requirements are met, and this can present problems for meeting the requirements for other nutrients. Thus, nutritionists often formulate growing-finishing diets using a ratio of individual nutrients to energy (i.e. g of lysine:calories) to adjust for the differences in FI when dietary energy content is varied.

Williams et al. (1994) and King et al. (2005) reported that when energy intake for finishing pigs was restricted, there was a linear decrease in average daily gain (ADG). This illustrates that growth is negatively impacted when pigs are unable to consume enough energy to meet their caloric requirements for maximum growth (King et al., 2005). For pigs provided ad libitum access to feed, energy intake can be restricted by gut capacity when pigs are fed low energy diets (Whittemore et al., 2003).

In the first trial of her experiment, Beaulieu et al. (2009) reported that decreasing dietary energy concentration from 3.57 to 3.09 Mcal of DE/kg resulted in a linear decrease in caloric intake (Mcal of DE/d), and as caloric intake decreased, there was a linear decrease in growth. Similar results were observed by Hinson et al. (2001), Kil et al. (2011) and Quiniou and Noblet (2012). In the second trial, Beaulieu et al. (2009) reported that pigs on a low energy diet compensated with increased FI and no differences were found in daily energy intake or growth. Smith et al. (1999) and Weber et al. (2006) also observed that pigs increased FI when fed diets with lower energy concentrations but had comparable caloric intakes and thus no effect of dietary energy concentration on growth (Table 1.1).

1.2.3. Effect of dietary energy on feed efficiency

Feed efficiency is the ratio of growth to FI (gain:feed; wt:wt) and, therefore, a change in either FI or growth, or both, will affect feed G:F. Using a "weight to weight" determination of G:F does not account for changes in dietary energy. A better measurement of G:F is the Mcal of energy per unit gain which adjusts for changes in the dietary energy concentration (Patience, 2012). De La Llata et al. (2001a) showed that as dietary energy concentration decreased from 3.61 to 3.35 ME Mcal/kg, G:F decreased from 0.31 to 0.27 in the late finishing phase (93 to 120 kg BW). In this phase, FI decreased as dietary energy concentration increased but caloric intake and growth remained unaffected. Similar results were reported by Smith et al. (1999), Apple et al. (2004), and Weber et al. (2006). If growth is depressed due to decreased energy intake and FI is increased, there will be a dramatic decline in G:F (Beaulieu et al., 2009; Hinson et al., 2011; Quiniou and Noblet, 2012). In summary, all studies mentioned in this section concluded that G:F (wt:wt) decreased when dietary energy concentration decreased.

1.2.4. Effect of dietary energy on caloric efficiency

As mentioned previously, the ratio of Mcal of energy to unit of BW gain is a more accurate description of the utilization of feed energy for growth. Quiniou and Noblet (2012) found that as dietary energy increased, there was a linear improvement in caloric efficiency when using ME and DE measurements. However, when energy was expressed using NE, there was no difference in caloric efficiency. The NE measurement accounts for the efficiency of utilization of ME. The gain per Mcal of NE allows for the calculation of caloric efficiency based on the calories that were actually available to the pig for maintenance and growth.

1.2.5. Effect of dietary energy on carcass characteristics

Dressing percentage, carcass weight, meat quality, and carcass composition are important factors determining the economics of pork production. Body composition reflects protein, fat, mineral, and water deposition. The relationship between protein and lipid deposition with changing energy intake in finishing pigs is described in Fig. 1.3. Protein deposition (PD) response to energy intake follows a curvilinear-plateau pattern where there is a curvilinear increase in the rate of PD until PD is maximized and plateaus (PD_{max}; Quiniou et al., 1996, Quiniou et al., 1999, van Milgen et al., 2008). Lipid deposition (LD) follows a curvilinear-linear increase as energy intake increases until PD_{max} is reached, then LD follows a linear increase as energy intake increases (van Milgen et al., 2008).

Hinson (2011) observed that when energy intake was reduced from 11.42 to 9.95 Mcal ME/d, hot carcass weights (HCW) were reduced, 10^{th} rib backfat depth (mm) was decreased, but carcass dressing percentage (carcass weight kg/live market weight kg) was unaffected. Beaulieu et al. (2009) and Quiniou and Noblet (2012) reported that when energy intake was reduced, there was a decrease in dressing percentage, HCW, and backfat depth (mm). However, when pigs were able to maintain a similar energy intake despite consuming diets containing 3.34 to 3.61 Mcal ME/kg, De La Llata et al. (2001) saw no effect of dietary energy concentration on dressing percentage or backfat depth (mm), but there was an increase in carcass weight when dietary energy was increased. Similarly, Quiniou and Noblet (2012) reported that there was a significant increase in carcass weight when dietary energy was increased from 2.22 to 2.65 Mcal of NE/kg, even though these treatments did not result in differences in energy intake (Mcal/day). Dietary fiber is often used as a research tool to decrease dietary energy concentration (Tokach et al., 2012). Using this dietary manipulation, Asmus et al. (2014) decreased dietary energy concentration from 3.33 to 3.27 Mcal of ME/kg and observed a decrease in back fat and an increase in large intestine weights which lead to a decrease in dressing percentage.

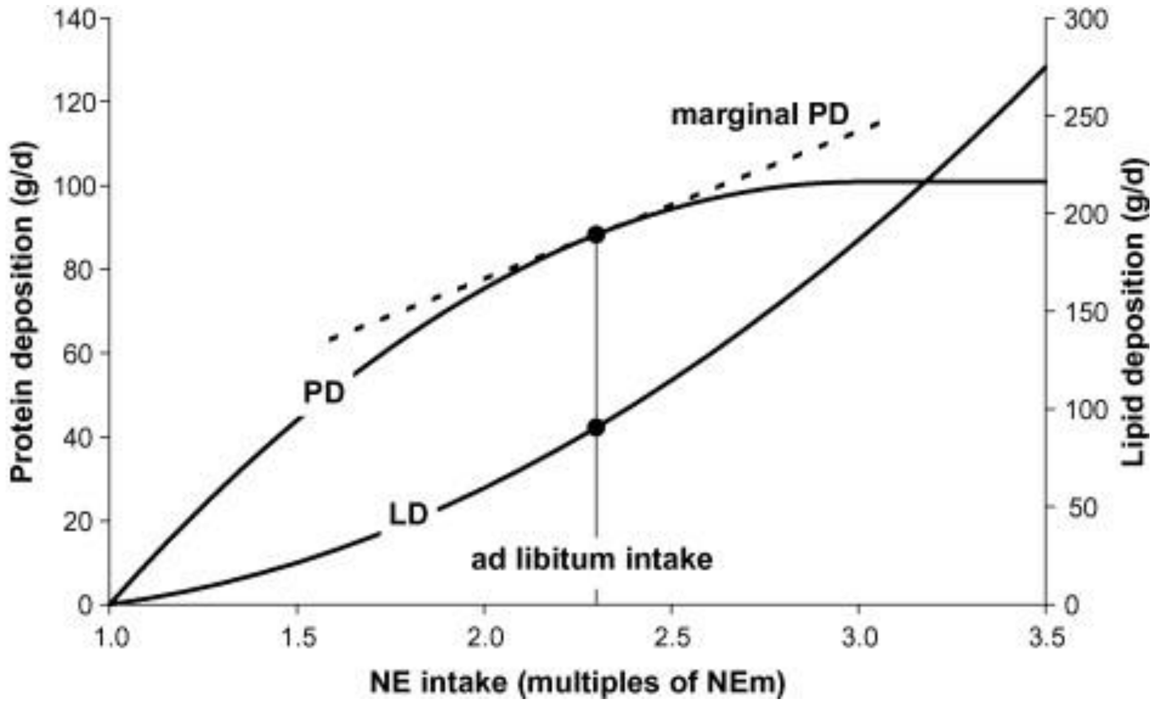

Figure 1.3. Protein deposition (PD) and lipid deposition (LD) at ad libitum intake (●) and the response curves of PD and LD to a changing energy supply (solid lines). Partitioning of energy is parameterized through the ad libitum NE intake, and the corresponding PD (van Milgen et al., 2008). Used with permission.

1.2.6. Dietary energy economics

Feed represents the greatest proportion of production costs, and higher energy feedstuffs tend to cost more. Increasing dietary energy concentration usually increases overall diet cost. The G:F ratio can be improved by increasing nutrient concentration, however, this does not always result in increased gains or profits for the producer (Beaulieu et al., 2009). The goal of the producer is to maximize returns on their investment and dietary energy is a major component of dietary costs.

Income over feed cost is the best criterion to use to optimize dietary energy in order to maximize net returns (De La Llata et al., 2001b). This measure ensures that the investment in feed optimizes growth to maximize economic returns (Beaulieu et al., 2009). Beaulieu et al. (2009) reported that when dietary energy was increased from 3.09 to 3.57 Mcal of ME/kg, G:F was improved. However, returns over feed cost were maximized with the lower energy diet. In contrast, De La Llata et al. (2001a) reported that increasing dietary energy improved growth, G:F, and IOFC. Differences in the ratio between feed cost and carcass prices could explain the difference in results between these two experiments, illustrating that optimal dietary energy is not necessarily a fixed value.

1.3. Stocking density

Space allowance can be decreased by increasing stocking density (pigs per pen) or reducing pen size. In conventional pork production, space allowance is altered by changing stocking density. Stocking density has negative impacts on welfare and performance of pigs with the potential to alter FI, growth, feeding behavior, aggression, stress, and economic sustainability (Brumm et al., 2008).

Space allowance is commonly expressed as space per pig (e.g. m^2/pig). In most commercial facilities, space allowance does not change simultaneously as the animal grows (Gonyou et al., 2006). As a pig grows, the increase in body surface area is nonlinear to the increase in weight. Using m^2/pig or m^2/kg BW as a measurement of space allowance does not account for the relationship between surface area and growth. Petherick and Baxter (1981) proposed an allometric equation (Eq. 1.6) to define space allowance.

$$\boldsymbol{k = A \div \mathrm{BW}^{.667}} \qquad 1.7$$

Where k represents a space allowance coefficient, A represents area (m^2), and $BW^{.667}$ is the metabolic body size in kilograms.

The k-value coefficient allows for the determination of space allowance independent of BW. A critical k-value is determined by evaluation of pig performance and defined as the point at which space allowance negatively affects growth (Fig. 1.4). A pen with a k-value below the critical k-value is considered crowded. Gonyou et al. (2006) conducted a review of the literature and then applied a broken-line analysis to the results (Fig. 1.4) to determine a critical k-value for grow-finish pigs (20 to135 kg BW). He reported that the critical k-value for finishing pigs on fully slatted floors is 0.0336. Previously, the Canadian Code of Practice for the Care and Handling of Pigs recommended a k-value of 0.035 in growing-finishing pens (Agriculture and Agri-Food Canada, 1993). In March 2014, the National Farm Animal Care Council established a new *Canadian Code of Practice for the Care and Handling of Pigs* which requires a *k* value of 0.0335 in grow-finish pigs raised on fully slatted floors, effectively decreasing the minimum required floor space allowance from the previous code of practice (NAFCC, 2014).

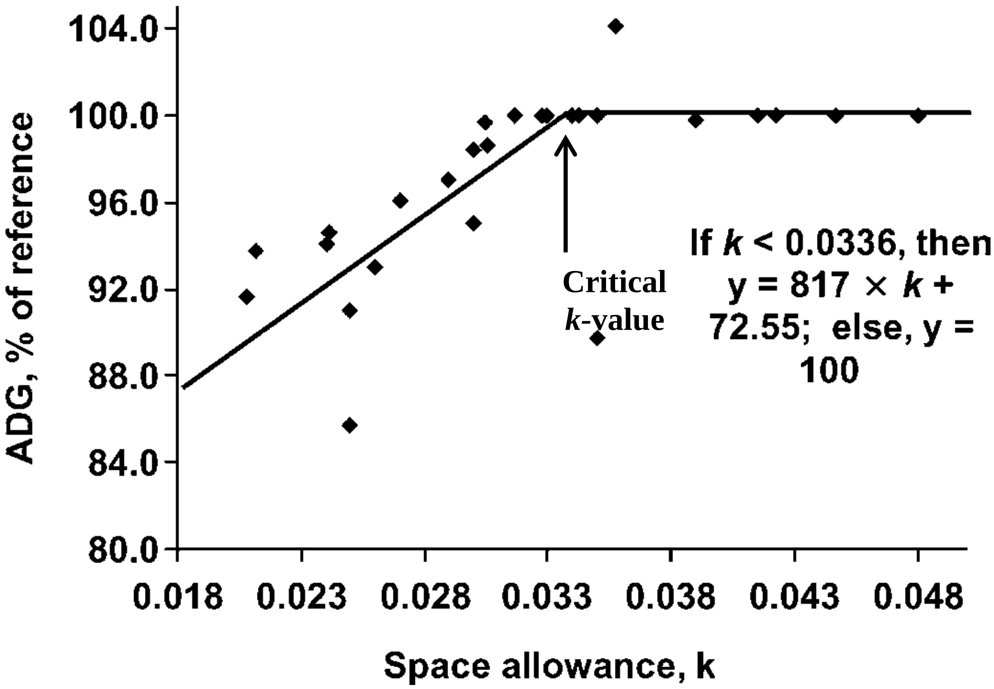

Figure 1.4. Broken-line analysis of ADG for grower-finisher pigs (adapted from Gonyou et al., 2006). Broken-line analysis provides a break point where above the point there is no change in the dependent variable and below the break point there is a linear reduction in the dependent variable. In this case, the breakpoint is referred to as the critical *k*-value and the dependent variable (y) is ADG. The ADG of the most spacious treatment within each experiment was used as the reference for comparison with the crowded treatment. Gonyou et al. (2006) reviewed the literature and applied a broken line analysis to the results of all the experiments to determine an overall critical *k*-value of growing-finishing (20 to 135 kg BW) production.

1.3.1. Effect of space allowance on feed intake, growth, and feed efficiency

The work of Gehlbach et al. (1966) was one of the earliest studies to investigate the effect of space allowance in a commercial finishing swine operation on FI. They concluded that an indication of crowding was a reduction in FI. Others have since reported that FI is reduced with decreased space allowance (Brumm and Miller, 1996; Edmonds et al., 1998; Gonyou and Stricklin, 1998; Brumm et al., 2001; Brumm, 2004; Brumm et al., 2004; Potter et al., 2010).

Gonyou and Stricklin (1998) reported that when the *k*-value decreased from 0.048 to 0.030, FI decreased by 4%. Despite providing additional feeder space, Potter et al. (2010) reported that increasing stocking density resulted in a reduction in FI. The reduction in FI is therefore, not due to limited feeder space. All of the previously mentioned studies used at least 1 treatment with a *k*-value below the critical *k*-value of 0.034 established by Gonyou et al. (2006).

Results have consistently shown that when space allowance is decreased, there is a reduction in growth that follows the reduction in FI (Gehlbach et al., 1966; Brumm and Miller, 1996; Edmonds et al., 1998; Gonyou and Stricklin, 1998; Brumm et al., 2001; Brumm, 2004; Brumm et al., 2004; DeDecker et al., 2005; Potter et al., 2010).

The effect of space allowance on G:F is less predictable due to the response of both growth and FI (Brumm et al., 2008). The effects of crowding, as discussed above, indicates that both FI and growth decrease as space allowance decreases. If both FI and growth change at an equal rate, G:F will remain unaffected (Gehlbach et al., 1966; Gonyou and Stricklin, 1998; Brumm et al., 2001; Brumm, 2004; Brumm et al., 2004; Potter et al., 2010). Conversely, if one of these two variables changes more rapidly than the other, there will be a change in G:F. For example, Edmonds et al. (1998) reported that when space allowance was decreased by 26%, ADG and FI were reduced by 15.5% and 10% respectively, thus G:F was reduced by 6.7%.

Although the effect of space allowance on FI and growth are well established, the cause for these reductions has not been elucidated. Brumm et al. (2008) stated "*It is not clear whether a reduction in feed intake causes a decline in daily gain, or whether a decline in daily gain results in a reduction in daily feed intake.*" Furthermore, he provided a possible explanation for how growth decreases FI; "*When pigs are crowded, their potential for lean growth is decreased, resulting in a decrease in feed intake*". Growth potential describes the maximum growth rate that a pig can achieve. The decreased in growth decreases the pigs' demand for nutrients; thus, the animal requires less feed.

1.3.2. Economics of space allowance

Choosing a stocking density is a critical decision for producers, as it affects enterprise profitability. In a study conducted by Anil et al. (2007), it was shown that when the *k*-value decreased from 0.036 to 0.027 in growing-finishing pigs (30 to 118 kg BW), space allowance was decreased by 27.3%, and ADG was decreased by 8.2%. However, decreasing the space allowance by 27.3% resulted in a 26.4% increase in daily gain per m^2 floor space. Even though they saw decreased growth of individual pigs, total kg of gain per pen was increased with the reduced space allowance. These results are in agreement with DeDecker et al. (2005), where reduced growth was observed with decreasing space allowance in wean to finishing pens (5 to 117 kg BW), but total live-weight production per pen increased. The results from these studies indicate that there is an increase in barn throughput when stocking density is increased, resulting in more pork produced.

1.3.3. Effects of space allowance on feeding behavior

Feeding behavior commonly includes observations of meal duration, number of meals, and calculation of consumption rate. Total meal duration and number of meals were decreased when pigs were crowded (k = 0.025) in the late finishing phase (95 kg BW; Street and Gonyou, 2008). Furthermore, crowded pigs did not increase feed consumption to maintain a FI comparable to uncrowded pens. Hyun et al. (1998) showed that when floor space is restricted in a noncompetitive feeding system, pigs will eat fewer meals but of longer duration, thus feed consumed per visit increases, resulting in similar FI relative to the uncrowded pigs. The non-competitive feeding system used in their study protected pigs while eating, and allowed them to remain at the feeder without being forced out by other pigs. The study conducted by Street and Gonyou (2008) used a competitive feeding system where pigs were vulnerable to other pigs competing for feeding space. The differences in meal duration between Hyun et al. (1998) and Street and Gonyou (2008) could be due to differences in the feeding systems.

1.3.4. Effects of space allowance on aggression, stress, injuries and mortality

Aggression, stress, injuries, and mortalities are key factors used to assess animal welfare. Results from studies performed to investigate the impact of space allowance on stress and aggression in finishing pigs have been variable. Street and Gonyou (2008) reported that despite a decrease in space allowance from 0.78 to 0.52 m^2 per pig, and a k-value of 0.025, there was no impact on injuries, mortality, or stress (estimated using salivary cortisol concentrations). They also examined adrenal gland morphology as an indicator of chronic stress and saw no differences in adrenal gland weight or medulla to cortex ratio as space allowance was decreased. Contrary to the results of Street and Gonyou (2008), DeDecker et al. (2005) showed a linear increase in animal mortality and morbidity when space allowance was decreased from 0.79 to 0.54 m^2 in pigs from 5 to 117 kg BW (*k* value at 70 kg BW =0.0335). Similarly, Anil et al. (2007) observed that decreasing space allowance from 0.88 to 0.64 m^2 (*k* value at 83 kg BW =0.0335) increased the occurrence of injuries and aggressive interactions, but did not increase stress (salivary cortisol measurements) in grower-finisher pigs (30 to 118 kg BW). The lack of a stress response may be because pigs had adjusted to the situation. DeDecker et al. (2005) and Anil et al. (2007), both observed a linear increase in production efficiency per pen (ADG/m^2) as stocking density increased. Anil et al. (2007) concluded that when evaluating production per unit area, animal welfare and the economics of production are often inversely related.

1.4. Interaction of stocking density and dietary energy

As stated in previous sections, FI is decreased when pigs become crowded causing a reduction in growth. Increasing the dietary energy concentration of the diet reduces the amount of feed required to meet the energy demands of the pig. Feeding crowded pigs a high energy diet should allow the pigs to increase caloric intake and therefore may mitigate the negative effects of crowding on growth.

In this review of the literature, only one study was found that investigated the interaction of space allowance and dietary energy concentration on finishing pig performance. Brumm and Miller (1998) examined this interaction in partially slatted growing-finishing pens in 3 different trials. Trial 1 also examined the lysine to energy ratio and the effect of season. Trials 2 and 3 examined only the effects of dietary energy and stocking density. Trial 2 used choice white grease and trial 3 used tallow to increase the energy concentration of the diet. Dietary energy concentration ranged from approximately 3.29 to 3.50 Mcal of ME/kg and diets were fed from 20 to 108 kg BW. Pigs were provided ad-libitum access to feed and all diets provided nutrients which met or exceeded requirements for pigs at each phase of growth. In all trials, pigs were stocked at a rate of 14 or 10 pigs per pen providing 0.56 and 0.78 m^2 respectively (k = 0.026 and 0.035 at 100 kg BW, respectively).

In trial 1, as space allowance decreased, there was a decrease in growth and FI with no effect on G:F. As dietary energy concentration increased, there was a reduction in FI and an improvement in G:F.

In trial 2, growth was increased with no effect on FI as space allowance decreased, thus G:F increased. As dietary energy increased, there was a reduction in growth and FI and G:F improved. Caloric intake (ME, Mcal/day) was unaffected by space allowance or dietary energy concentration when measured in 20 to 114 kg BW pigs. However, in the late finishing (82 to 106 kg BW) phase, there was a linear increase in caloric intake as dietary energy concentration increased.

Average daily gain was reduced and there was a tendency for FI to increase when space allowance was decreased in trial 3. When dietary energy concentration increased, growth was improved and FI was reduced and therefore G:F improved.

In all 3 trials, an interaction between dietary energy concentration and stocking density was not observed for any of the parameters measured. Brumm and Miller (1996) concluded that the negative effects of crowding cannot be mitigated by increasing the dietary energy concentration. They did not investigate the effects of this interaction on economics, stress or feeding behavior. More research is required to determine if interactions exist between dietary energy and stocking density on finishing pig performance, economics, welfare, and feeding behavior.

1.5. Summary of literature review

Market volatility forces pork production systems to be flexible, while efficiently utilizing or reducing input costs. Since 2007, pork producers have seen an increase in grain prices which have driven feed costs and total production costs higher. In response to market volatility, producers are adjusting diets and stocking density in an effort to remain profitable.

When dietary energy concentration is increased, FI is reduced, G:F is improved and growth is unaffected if caloric requirements are met. Increasing the dietary energy concentration allows pigs to meet the caloric requirement for growth with less feed. Crowding reduces FI, thus pigs consume fewer calories which results in a reduction in growth. However, crowding also alters feeding behavior, increases aggression, and jeopardizes animal welfare.

If the mechanism of crowding is a restriction of FI, offering a diet with increased energy concentration may decrease the negative effects. Theoretically, if pigs in crowded pens are able to consume the calories required for maximum growth rate, the negative effects on performance should be mitigated. However, the cost of increased dietary energy may lessen the benefits of the improved growth rate. Furthermore, the optimal dietary energy for increased returns may depend on stocking density. In an environment where pigs are given space in excess, they may be able to consume more feed, thus a low energy least cost diet may be the best option.

Understanding the relationship between dietary energy and stocking density will help pork producers maximize return on their investment. Moreover, it is vital for the industry to develop an understanding of the impact of crowding on the welfare and health of pigs while creating an economically viable option for producers.

2. Maximizing net income for pork producers by determining the interaction between dietary energy concentration and stocking density on finishing pig performance, welfare, and carcass composition

2.1. Introduction

The cost of raising pigs increased steadily from 2005 to 2013. Feed is currently the largest investment in pork production (Young, personal communication) and providing energy to the pig represents the greatest proportion of diet cost (Hinson et al., 2011). Since dietary energy is a key factor in diet cost, producers must supply energy at a level that maximizes income over feed cost (IOFC; De La Llata et al., 2001b). Previous research has demonstrated that G:F is improved when dietary energy concentration is increased (Smith et al., 1999; Apple et al., 2004; Beaulieu et al., 2009; Hinson et al., 2011; Quiniou and Noblet, 2012). However, the improvement in G:F may not be sufficient to offset the increased diet cost, and economic returns may decrease (Beaulieu et al., 2009). Producers can also improve net returns by increasing barn throughput which spreads the fixed costs over more kg of pork. As stocking density increases, space allowance (m^2/pig) is decreased, and FI and growth are often reduced (Gehlbach et al., 1966; Brumm and Miller, 1996; Edmonds et al., 1998; Gonyou and Stricklin, 1998; Brumm et al., 2001; Brumm, 2004; Brumm et al., 2004; Potter et al., 2010). However, despite the negative impact on the performance of the individual pig (60 to 125 kg BW) economic returns are often improved. There are concerns that decreasing space allowance compromises pig welfare (DeDecker et al., 2005; Anil et al., 2007).

Supplying additional energy in a crowded environment may increase caloric intake and therefore mitigate the negative effects of crowding on growth. Brumm and Miller (1996) examined this interaction in partially slatted growing-finishing pens in 3 trials using corn soybean based diets. They concluded that the negative effects of crowding on FI were not alleviated by increasing the dietary energy concentration. They did not determine if there was an interaction of these factors on economics, or feeding behavior. The rate and efficiency at which pigs grow has improved greatly since Brumm and Miller (1996) completed their work. More research needs to be conducted to fully understand the interactive effects of space allowance and dietary energy on finishing pig performance, economics, welfare, and feeding behavior of fast growing pigs.

The overall objective of this project was to investigate the interaction between dietary energy and floor space allowance on net returns for swine producers, especially for those in Western Canada. Specifically, we wanted to determine the interaction between dietary net energy and floor space allowance (pigs per pen) on:

1. Overall farm returns
2. Feed intake and growth rate
3. Feed efficiency (defined as feed/kg gained, feed/lean pork produced, feed/net returns, caloric efficiency)
4. Variability in growth
5. Barn throughput

The second objective was to determine the interaction of dietary net energy and floor space allowance (pigs per pen) on pig welfare and feeding behavior. Specifically, we wanted to observe the effect of these factors on:

1. Feeding behavior
2. Aggression at the feeder
3. Stress
4. Prevalence of lameness and injuries
5. Mortalities

We hypothesized that the dietary NE concentration which maximized net returns to the producer would depend on stocking density.

2.2. Materials and methods

The protocol for this experiment was reviewed and approved by the Animal Research Ethics Board (Protocol #20120022) at the University of Saskatchewan and adhered to the Canadian Council on Animal Care guidelines for humane animal use (CCAC, 1993).

2.2.1. Experimental design

The experiment involved 18 treatments arranged as a 2 × 3 × 3 factorial, including: sex (barrows and gilts), dietary energy (2.15, 2.3 and 2.45 Mcal NE/kg) and stocking density (14, 17 or 20 pigs per pen providing 0.92, 0.76 and 0.65 m^2 per pig, respectively). Pens within a room were randomly assigned to a sex, stocking density, and dietary energy treatment. In total, 3 replications of the 18 treatments were completed using 54 pens providing an “n” of 18 for the main effects of stocking density and dietary energy, 27 for sex, 9 for the interaction of sex with stocking density or dietary energy, and an “n” of 6 for the interaction of stocking density and dietary energy. For the measurements of gastrointestinal weights, adrenal gland weights, and feeding behavior, only stocking densities of 14 and 20 pigs per pen and dietary energy concentrations of 2.15 and 2.45 Mcal NE/kg were used. From herein, these will be referred to as the subset pens.

2.2.2. Animals and environment

This experiment was conducted at the Prairie Swine Centre (Saskatoon, SK) from October, 2012 to June, 2013. Each room was 14.0 m long by 10.8 m wide and contained 10 rectangular 12.96 m^2 (4.8 m × 2.7 m) pens. The pens consisted of 1 concrete back wall, stainless steel partitions between pens, and 1 polyvinyl chloride (PVC) gate in front. The flooring was fully slatted concrete with a shallow manure pit beneath it. Each pen contained 2 single space, wet-dry feeders (Crystal Springs Hog Equipment; St. Agathe, MB, Canada) located at the front of the pen (1 on each side). Feeders provided each pen with approximately 0.22 m^2 of feeder space per pen and were used as the water source for these pens. Each room was equipped with a Proportional Environment Controller (Phason, Winnipeg, MB) to control the ventilation and temperature. A minimum ventilation value was set for each room to ensure fresh air circulation. Room temperatures were set at 15° C, and were regulated using negative pressure airflow and a propane heater. Temperature and humidity were monitored daily using 2 data loggers (HOBO, Onset; Cape Cod, MA). Lights were set on an automatic timer and were on from 0700 to 1700, providing 10 h of light/d. Rooms were washed and sanitized and manure pits were emptied before the animals entered.

In total, 918 finishing pigs (equally divided between barrows and gilts) were used in this study. A complete replication of all treatments could not be completed simultaneously due to a restriction in barn space and pig availability, so an incomplete block design was used. Rooms were filled and started on test at approximately 4 wk intervals. Each room contained 153 pigs and 306 pigs were used per replication. Pigs used in this experiment were offspring from a Camborough Plus dam and line 337 sire (PIC Canada Ltd.; Winnipeg, MB). Pigs were weaned at 26 ± 2 d of age and were housed in the nursery for 4 wk before being moved to the growing-finishing rooms. Pigs were randomly selected from all available pigs in a cohort, maintaining normal population variability (60 to 90 kg BW), age (within 3 wk of age), health, and growth rates. The pigs' weights were monitored for 2 wk prior to the start to ensure comparable growth rate. Pigs that had obvious health problems (lame, ridglings, intact males, prolapsed rectums, unthrifty, or hernias) were not selected for the study. Pens were randomly assigned to treatment. Pigs were randomly assigned to pens within sex and to achieve an average initial BW of 75 kg. After placement in the appropriate pen, pigs were provided a common diet for at least 3 d prior to starting the experiment. On experimental d 0, pigs were weighed and feeders were cleaned and filled with the appropriate diet. Pigs were kept in the pens until they reached slaughter weight. Pigs were marketed weekly and were sent to slaughter when they reached a BW of 115 kg. Pigs were transported (4 h) to Thunder Creek Pork Inc. (Moose Jaw, SK.) for slaughter.

2.2.3. Diets

Diets were designed to be typical of those used in Western Canada. To ensure that nutrient requirements were met but nutrient levels were not excessive, barrows and gilts were phase fed individually, 3 diets each over the experimental period. However, the number of diets was minimized by using diet sets 2 and 3 for both barrow and gilts (Table 2.1). The first 3 diet sets (a set includes all energy treatments) were fed as the 3 finishing phases for gilts, and diet sets 2 to 4 were used as the 3 finishing barrow phases (Table 2.1).

Table 2.1. Arrangement of diets used for barrows and gilts to facilitate phase feeding

	Diet set			
Sex and BW	1	2	3	4
Gilts	Phase 1	Phase 2	Phase 3	
BW range, kg	75 to 90 kg	90 to 105 kg	105 kg to market	
Barrows		Phase 1	Phase 2	Phase 3
BW range, kg		75 to 90 kg	90 to 105 kg	105 kg to market

A total of 12 diets were required for this study; 4 sets of diets with 3 dietary energy levels within each diet set. Phase changes occurred when the pen average reached the desired weight. The first phase was fed to pens with an average weight of 75 to 90 kg, the second phase was fed to 90 to 105 kg pigs, and the third phase was fed to pigs from 105 kg to market (Table 2.1)

The experimental diets (Table 2.2a/b) were wheat and barley based, and formulated to meet or exceed nutrient requirements as defined by the National Research Council, (2012). All diets contained the same amount of vitamin and mineral premix, choline chloride, salt, and phytase (RONOZYME® NP; DSM, Heerlen, Netherlands). Limestone and synthetic amino acids (AA) were used to balance within diet sets for Ca, lysine, methionine, tryptophan, and threonine. The SID lysine:NE ratio was kept constant for each set of diets. Diatomaceous earth (Celite, Celite Corporation, Lompoc, CA) was added to the diets (0.4%) as a source of acid insoluble ash (AIA), and was used as a marker to allow for the estimation of nutrient digestibility. Ingredient nutrient profiles for grains and tallow were obtained from the Nutrient Requirements of Swine (National Research Council, 2012). Label nutrient values were used for the composition of synthetic AA, vitamin and mineral premix, salt, limestone, calcium phosphate, choline chloride, and phytase. Altering dietary energy was accomplished by varying grain sources (i.e. wheat and oat hulls), and final adjustments were made using tallow.

Diets were supplied ad libitum but were weighed when added to the feeder. Diets were mixed at a commercial feed mill (Masterfeeds, Saskatoon, Sk.) and stored on site at the Prairie Swine Centre. Feed was augured into plastic trash cans then weighed and added to feeders. Feed was added each morning, and feeders were checked again each evening to ensure a constant supply.

Table 2.2a. Ingredient composition of the diets formulated to contain 2.15, 2.30, and 2.45 Mcal of NE/kg fed to both sexes (as-fed basis)[1,2,3]

	Diet Set, #											
	1			2			3			4		
	NE, Mcal/kg											
	2.15	2.30	2.45	2.15	2.30	2.45	2.15	2.30	2.45	2.15	2.30	2.45
Ingredient, %	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Barley	48.83	27.31	5.79	54.84	41.76	30.36	66.55	58.41	50.27	68.8	65.29	61.81
Wheat	-	25.03	50.06	-	15.17	28.66	-	9.32	18.64	2.94	8.97	15.00
Millrun wheat	20.00	20.00	20.00	20.00	20.00	20.00	14.41	14.70	15.00	5.00	7.52	10.00
Peas	18.97	18.82	18.66	14.47	14.74	15.00	7.70	8.85	10.0	6.65	6.98	7.33
Oat hulls	7.37	3.68	-	7.89	3.95	-	8.53	4.27	-	13.08	6.54	-
Canola meal	2.00	1.00	-	-	-	-	-	-	-	-	-	-
Limestone	0.91	0.99	1.08	0.86	0.93	0.99	0.83	0.89	0.95	0.70	0.79	0.88
Tallow	0.50	1.65	2.8	0.5	1.95	3.41	0.50	2.04	3.57	1.37	2.41	3.45
Vitamin premix [2]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Mineral premix [3]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Celite [4]	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Salt	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Phytase [5]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Choline chloride	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
L-Tryptophan 98%	0.01	-	-	-	-	-	-	-	-	-	-	-
Lysine HCL 78%	0.19	0.26	0.32	0.21	0.26	0.30	0.26	0.28	0.31	0.25	0.27	0.30
L-Threonine 98%	0.08	0.10	0.12	0.09	0.10	0.12	0.10	0.11	0.12	0.10	0.11	0.11
DL-Methionine 98%	0.03	0.04	0.05	0.02	0.03	0.04	0.01	0.02	0.03	-	0.01	0.01

[1] All diets were formulated to meet requirements for pigs of each phase (National Research Council, 2012)

[2] Minerals were supplemented to supply Co at 0.5 ppm, Cu 20 ppm, I 1 ppm, Fe 150 ppm, Mn 75 ppm, Se 0.3 ppm, and Zn 150 ppm per kg of feed.

[3] Vitamin were supplemented to supply 8,000 IU of vitamin A, 1,000 IU of vitamin D, 20,000 of vitamin E, 1.5 IU of vitamin K, biotin 0.1 IU, choline 130 IU, niacin 20 IU, pantothenic acid 15 IU, riboflavin 4 IU, and 20 IU of vitamin B_{12} per kg of feed.

[4] Celite (Celite Corp., Lompoc, CA) was added to the diet at 0.40 % and is diatomaceous earth used as an insoluble marker

[5] Ronozyme® NP; DSM, Heerlen, Netherlands; 10,000 FTU /g

Table 2.2b. Nutrient composition of the diets formulated to contain 2.15, 2.30, and 2.45 Mcal of NE/kg fed to both sexes (as-fed basis)

	Diet Set, #											
	1			2			3			4		
	NE, Mcal/kg											
	2.15	2.30	2.45	2.15	2.30	2.45	2.15	2.30	2.45	2.15	2.30	2.45
Calculated composition	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
ME, Mcal/kg	2.95	3.10	3.24	2.93	3.09	3.24	2.91	3.07	3.22	2.90	3.06	3.21
NE, Mcal/kg	2.15	2.30	2.45	2.15	2.30	2.45	2.15	2.30	2.45	2.15	2.30	2.45
Crude protein, %	14.06	14.83	15.6	13.02	13.76	14.49	12.04	12.7	13.37	11.14	11.94	12.75
SID lysine g/Mcal of NE[1]	3.23	3.23	3.23	2.97	2.97	2.97	2.73	2.73	2.73	2.52	2.52	2.52
Ca, %	0.60	0.60	0.60	0.56	0.56	0.56	0.53	0.53	0.53	0.50	0.50	0.50
Available P, %	0.25	0.25	0.25	0.24	0.24	0.24	0.23	0.23	0.23	0.23	0.23	0.23
Measured composition												
NE, Mcal/kg	1.70	2.04	2.24	1.86	1.97	2.23	1.88	2.15	2.16	1.62	1.86	2.18
Crude protein, %	13.30	14.82	16.40	13.42	13.19	14.64	12.24	12.11	12.98	11.53	12.17	12.12
Ether extract, %	2.15	2.79	3.99	1.89	3.19	4.39	1.99	2.99	4.40	2.49	3.20	3.80
Starch, %	33.23	37.58	40.76	37.33	36.96	36.87	37.91	39.13	36.94	35.43	41.21	43.77
Acid detergent fiber, %	11.00	8.59	6.42	9.84	8.55	7.05	10.03	8.08	9.04	10.58	9.27	6.32

[1] Standardized ileal digestible lysine

2.2.4. Stocking density

Each pen provided 12.96 m^2 of space not including the space that feeders occupied (0.16 m^2 per feeder), providing pigs with 0.93, 0.76, and 0.65 m^2/pig for the stocking densities of 14, 17, and 20 pigs/pen respectively (Table 2.3). The Canadian Code of Practice for the Care and Handling of Pigs (March 2014) defines crowding as a *k*-value lower than 0.0335. Therefore, the pen containing 14 pigs was never considered crowded as it never reached a *k*-value of less than 0.0335. The pen of 20 was considered the most crowded, pigs in these pens were below a *k*-value of 0.0335 when the average pen weight was 85 kg BW. The pen of 17 was considered crowded when the pen average BW was 108 kg. Space allowance was not adjusted when pigs were removed.

Table 2.3. Space allowance and k-value for each stocking density at various weights throughout the finishing period (75 to 118 kg BW)

		Stocking Density		
		14	17	20
			Area/pig, m^2	
		0.93	0.76	0.65
			k-values	
BW , kg	75	0.0520	0.0428	0.0364
	85	0.0478	0.0394	**0.0335**
	108	0.0405	**0.0334**	0.0284
	118	0.0384	0.0316	0.0269

2.2.5. Marketing

Pigs were marketed once a week, and selected for market to ensure an average BW of 120 kg. In order to achieve a 120 kg average market weight, pigs that weighed more than 115 kg BW were sent to slaughter. They were weighed on the day of marketing. Neither food nor water was withheld from pigs prior to loading on the truck. Pigs were transported 4 h to Thunder Creek Pork Inc. (commercial abattoir; Moose Jaw, SK) and then placed in holding pens overnight (12 h) where they were provided with water but not food. A “room pull” was defined as the removal of 15 (10%) or more pigs from a room for market. From the first official pull, the room had 3 more weeks until all pigs were sent to market.

2.2.6. Health

Each pen was observed a minimum of 2 times per day to ensure adequate food and water, and that all pigs were mobile and healthy. Any pig that appeared to be ill or injured was noted, and observations increased for the next 7 days but no medications were given to pigs on test. If the pig's health did not improve, it was removed from the study and treated as per normal barn procedure. Pigs that did not gain weight for 2 consecutive weeks were assumed to be ill and removed from the study. Any unexpected change in management (i.e., no or poor water flow, empty feeders, change in room environment) was recorded. Any pig that died or was euthanized because of ill-health was weighed and sent for necropsy (Prairie Diagnostics Services Inc.; Saskatoon, SK). Stocking density was not corrected after pigs were removed from a pen, in order to mimic what would happen in a commercial facility.

2.2.7. Injury scoring

All pigs were evaluated for lameness (4 point scoring system) and injury (scratches, tail bites, flank bites and leg lesions) when weighed, using the scoring system developed by Street et al. (2008; Table 2.4). Two people observed the pigs weekly when the animals walked away from the scale. The scores from each category were averaged on a pen basis.

Table 2.4. List of injuries and corresponding meanings[1]

Type of injury	Score	Description
Flank bite	0	no injury present
	1	hair is worn off of area
	2	redness or inflammation present
	3	outer layer of skin has been removed
	4	scabbing has formed over the wound
	5	severe wound, inflammation surrounding the area
Tail bite	0	no injury present
	1	minimal injury but signs of chewing visible
	2	visible blood from open wound
	3	outer layer of skin removed
	4	severe swelling and redness or tail necrosis
Lameness	0	no injury present
	1	leg is swollen and red; pig does not favor the leg
	2	pig does not bear full weight on leg but puts foot down
	3	pig avoids putting foot down
Leg lesion	0	no injury present
	1	swollen joint visible
	2	abscess visible on joint
	3	beginning of a small open wound
	4	scabbing has formed over the wound
	5	large open wound is present
Leg bursa	Y	no bursa present
	N	presence of 1 or both leg bursa on olecranon joint

[1] Street et al., 2008

2.2.8. Performance measurements

Individual pig weights were taken on d 0 and then weekly until the room was emptied to allow for the determination of average and variation of growth rate (coefficient of variation, CV) within a pen. Pen growth rate was calculated by averaging the individual growth rates of pigs in that pen. Growth rates were determined by subtracting the previous weight from the current weight and then dividing by the number of days between weigh days.

Feed additions were weighed and recorded. Feed remaining on weigh days and phase changes was removed from the feeder and weighed to allow for the calculation of FI per pen. The scale for weighing pigs had a tolerance of 0.5 kg and the feed scale had a tolerance of 0.1 kg. Scales were checked for accuracy prior to each use using calibrated weights.

2.2.9. Sampling

Fecal samples were collected 1 wk after each diet change. Samples were obtained as the pig was excreting feces or directly after defecation to ensure a fresh sample. A daily fecal sample was composed of samples from 2 to 3 pigs per pen. Samples were stored in a freezer at -20°C.

Samples of all diets were obtained at the feed mill for each batch and again at the barn, as feed was augured into the barn. A composite sample was created for each diet using equal portions of all the samples that were collected for a given diet. Diet samples were stored in a cool, dry environment until analysis was completed.

2.2.10. Analytical methods

Analysis of the diets was conducted by a commercial laboratory (Central Testing Laboratory Ltd., Winnipeg, Manitoba, Canada). Composite samples were analyzed for crude protein (AOAC, 990.03), acid detergent fiber (ANKOM technology method 5 08-16-06), fat (AOCS, Am 5-04) , starch (UV method as outlined by Albalashmen et al., 2012) and dry matter (AOAC, 903.15).

Fecal samples were freeze dried until moisture was no longer visible or detected by touch using a shelf and condenser temperature of 30°C and -40°C, respectively (VirTis 25ES, SP Industries, Gardiner, NY). Diet and fecal samples were prepared for chemical analysis by grinding through a 1-mm screen in a Retsch Mill (Retsch Model ZM1; Brinkman Instrument of Canada Ltd., Rexdale, ON).

Dry matter (DM) for all samples was determined by drying samples at 135°C for 2 h in a drying oven with forced convection (AOAC, 930.15).

Samples (1.0 g fecal and 2.0 g of feed) were analyzed for AIA using a modification of the procedure of McCarthy et al. (1974). Samples were weighed and ashed in a muffle oven at 500°C for 24 h. Samples were then digested with 4 M HCl at 120°C for 80 min, and then centrifuged at 2500 rpm (1295 × *g*) for 10 min. Supernatant samples were rinsed with distilled water three times and then dried at 80°C until there was no visible moisture. Samples were then ashed at 500°C for 24 h, weighed, and AIA content calculated as the difference.

Gross energy content of the feed and feces was determined using an adiabatic bomb calorimeter (Model 1281, Parr Instruments, Moline, IL.) with benzoic acid as the calibration standard. Benzoic acid samples were required to be 6318 ± 31.6 Mcal, or a variance of less than 3% before experimental sample analysis began.

Analysis of all samples was performed in duplicate, and the error between duplicates for AIA was less than 10% and the error for GE and DM were less than 3%.

2.2.11. Diet analysis

Apparent energy digestibility was determined on a dry matter basis using the following equation:

$$D_{AD}\% = \mathbf{100}\% - [(\boldsymbol{M_d} \times \boldsymbol{GE_f})/(\boldsymbol{M_f} \times \boldsymbol{GE_d}) \times \mathbf{100}] \tag{2.8}$$

Where D_{AD} is the apparent total tract digestibility coefficient for dietary energy, M_d is the concentration of indigestible marker in the diet, GE_f is the gross energy contained in the feces, M_f is the concentration of indigestible marker in the feces, and GE_d is the amount of GE contained in the diet. All numbers were on a DM basis.

Digestible energy content was calculated with the following equation:

$$\boldsymbol{DE} = \boldsymbol{D_{AD}}\% \times \boldsymbol{GE_d} \tag{2.9}$$

Using the calculated DE, an estimation of dietary NE was calculated; using the equation (National Research Council, 2012):

$$\boldsymbol{NE = (0.70 \times DE) + (1.61 \times EE) + (0.48 \times Starch) - (0.91 \times CP) - (0.87 \times ADF)} \tag{2.10}$$

Where NE is the net energy in the diet (kcal/kg), EE is the ether extract and represents the concentration of lipids in the diet, CP is crude protein, ADF is acid detergent fiber, and all values are expressed as g/kg.

Net energy intake was calculated by multiplying NE concentration as fed (Mcal/kg) by the ADFI (kg/day). Energy efficiency was determined by dividing ADG (kg/day) by NE intake (Mcal/day).

2.2.12. Carcass characteristics

Pigs were tattooed prior to shipping with a distinct number for each pen, allowing for the estimation of treatment effects on carcass characteristics. Carcasses were measured at the 10th rib for loin and back fat depth using an optical probe (Model PG-207, Viewtrak Technologies Inc., Edmonton, AB, Canada). Measured values were used to predict whole carcass lean yield. Estimated carcass lean yield was then combined with actual carcass weight to determine the grade index. Dressing percentage was equal to the sum of the live weight of pigs sent to slaughter divided by the sum of the carcass weights.

Gastrointestinal tract weights

Gastrointestinal tract (GIT) weights were only determined using pigs from the subset pens. Prior to slaughter, 2 pigs from each subset pen were ear tagged to identify them as they moved along the slaughter line. As the identified pigs were moving through the slaughter plant, the stomach, small intestine and large intestine were collected. The GIT was weighed full and was then separated into small intestine, large intestine, stomach, and excess mesenteric tissue. Each component was emptied, rinsed, patted dry, and then weighed empty. The difference between empty weight and full weight was defined as gut contents.

Adrenal gland collection

Adrenal glands were collected at slaughter from the same pigs used for GIT collection. Kidneys were left on the GIT allowing the adrenal glands to be easily located. Both the left and right adrenal glands were removed and trimmed of excess tissue. Glands were then placed in formalin (30.05% CH_2O in H_2O) until they were weighed. The left and right adrenal glands were patted with a paper towel to remove excess moisture and were then weighed using an analytical balance.

2.2.13. Feeding behavior

Behavior was monitored in the subset pens over a 24 h period 1 d prior to the first pig being marketed. A video and a still camera were mounted at the back of each pen, and focused on the two feeders at the front of the pen. Video was recorded from 0700 to 1700 h (light period). Still photos were taken every 2 min from 1700 h for a minimum of 5 h when the lights were off using flash photography.

Feeder aggression was measured from 0700 to 1700 h using the video footage. Feeder aggression was defined as any aggressive interaction used to gain access to or remain at the feeder. Aggressive interactions were only counted if 1 of the pigs was eating prior to the interaction. Any pigs (2 or more) that were fighting, biting, and/or aggressively pushing were counted as engaging in an aggressive interaction (Magowan et al., 2008). Cueing behaviors' such as nudging or mounting were not counted as an aggressive interaction. Displacement from the feeder due to the aggressive interaction was also recorded (Magowan et al., 2008).

Feeding behavior was observed using 1 h of video from 0900 to 1000. A pig with its snout in the trough or head in the feeder was considered to be eating (Magowan et al., 2008). Feeder visits were defined as any pig that appeared to be eating for at least 20 s. Visit duration was recorded to allow for the calculation of average bout duration, time spent at the feeder per pig, and total time spent at the feeder per pen.

The still photos were used to determine feeder usage at night. Photos were given a score of 2, 1, or 0 corresponding to both, 1 or 0 feeders occupied, respectively. Total nighttime score was then divided by the highest possible score to determine the nighttime feeder usage percentage.

2.2.14. Economic calculations

All economic data was calculated using pen averages and assumes that all pigs were raised in similar environments prior to 75 kg BW and growth up until 75 kg BW was the same for all pigs.

Feed prices were calculated using the 5 yr average (2009 to 2013 inclusive; Table A.1) for grain prices. Other ingredient prices were obtained from a commercial feed mill (Masterfeeds, Saskatoon, Sk.; August 2012). Costs per ton were used to make the following calculations:

Average feed cost/pig per day ($):

$$\boldsymbol{FC_d} = (\boldsymbol{ADFI_{P1}} \times \boldsymbol{FC_{P1}}) + (\boldsymbol{ADFI_{P2}} \times \boldsymbol{FC_{P2}}) + (\boldsymbol{ADFI_{P3}} \times \boldsymbol{FC_{P3}}) \tag{2.1}$$

Where FC_d is the average feed cost per pig/day, ADFI is average daily feed intake, $FC_{P\#}$ is the feed cost per kg of feed in that phase, and subscripts with a number signify the growth phase.

Average feed cost per pig ($; 75 to 118 kg BW):

$$\boldsymbol{FC_{pig}} = \frac{[(\boldsymbol{FCD_{P1}} \times \boldsymbol{Day_{P1}})+(\boldsymbol{FCD_{P2}} \times \boldsymbol{Day_{P2}})+(\boldsymbol{FCD_{P3}} \times \boldsymbol{Avgd_{P3}})]}{\boldsymbol{Days_{MRKT}}} \tag{2.2}$$

Where FC_{pig} is the average overall feed cost per pig, FCD is feed cost/pig per day, $Day_{P\#}$ is the days that pigs were on that phase, $Avgd_{P3}$ is the average number of days pigs were on phase 3, and $Days_{MRKT}$ is the average days to market.

Feed cost per pen ($):

$$\boldsymbol{FC_{pen}} = \boldsymbol{FC_{pig}} \times \boldsymbol{Stocking\ Density} \tag{2.3}$$

Where FC_{pen} is the total feed cost per pen and stocking density is the number of pigs per pen prior to any pigs being removed.

In order to calculate the effect of treatment on finisher barn flow on an annual basis, the growing-finishing model was based on a starting weight of 20 kg BW and a market weight of

118 kg BW. The value of 70 d was used as a constant for all pens, representing the number of days required for a pig to reach 75 kg BW. Annual finisher rotations were calculated using the following equation:

$$\boldsymbol{Finisher\ rotations = 365/(70 + Days_{MRKT})} \qquad 2.4$$

Calculated finisher rotations per year were used to calculate the annual pen throughput by multiplying the stocking density by the calculated finisher rotations. Pen throughput was then used to calculate annual feed cost by multiplying pen throughput by the FC_{pig}.

The 5 yr (2009 to 2013) average carcass price for Saskatchewan was used in the economic analysis (Animal Industry Market Information System, 2009 to 2013). Carcass revenue ($) was calculated on a pig (Eq. 2.5), pen (Eq. 2.6), and annual basis (Eq. 2.7).

$$\boldsymbol{CR_{pig} = \$144.98 \times Carcass\ (per\ 100\ kg)} \qquad 2.5$$

$$\boldsymbol{CR_{pen} = CR_{pig} \times Stocking\ density} \qquad 2.6$$

$$\boldsymbol{CR_{annual} = CR_{pig} \times Pen\ throughput} \qquad 2.7$$

Where CR is carcass revenue and $144.98 is the 5 yr average carcass price per 100kg.

Annual IOFC ($) was then calculated by subtracting annual feed cost from annual carcass revenue.

Using the performance of pigs in this study, a model was created to investigate the changes in IOFC under different market scenarios. We determined the effects of increasing or decreasing feed costs or pig prices, or when both change simultaneously. The FI required for pigs to reach market weight was multiplied by the feed cost for that specific scenario, and then multiplied by the barn throughput. Annual feed cost was then subtracted from the CR_{annual}. The model was based on the average performance of the pigs on each treatment. Results are reported as arithmetic means, and statistical analysis was not performed.

2.2.15. Statistical analysis

This experiment was designed as an incomplete block (Tempelman et al., 2009) with treatments arranged as a 2 × 3 × 3 factorial with 2 sexes (barrows and gilts), 3 NE levels (2.15, 2.30, and 2.45 Mcal NE/kg), and 3 stocking densities (14, 17, and 20 pig per pen). Treatments were randomly assigned to pens. There were 9 pens per room and 2 rooms that made up a complete replication of all treatment combinations. Each room had 3 pens per dietary energy treatment while also having 3 pens of each stocking density treatment except for the first repetition, where there were 4 pens of the 2.45 Mcal NE/kg treatment in room 1 and in room 2 there was 4 pens of the 2.30 Mcal NE/kg. Each repetition contained 9 pens of each sex, but rooms were not balanced for sex.

Performance, economic, and carcass characteristic data was analyzed as an incomplete block design using the MIXED procedure of SAS 9.2 (SAS Institute Inc., Cary, NC, USA) with pen as the experimental unit. Incomplete block designs are randomized block designs where all treatments are not represented in the block, but all treatments occur in a repetition (Tempelman et al., 2009). The statistical model included the fixed effects of sex, NE, and stocking density, and also included the following interactions: sex by NE, sex by stocking density, NE by stocking density. Pen and room were random effects. Orthogonal polynomial contrasts (linear and quadratic) were used to determine the response of the measured variable to dietary energy and stocking density. The initial statistical model used starting body weight as a covariate, but it was insignificant for all measured variables, thus it was removed from the model. Likewise, a three-way interaction of sex, dietary energy, and stocking density was in the initial model statement but it was found to be non-significant ($P > 0.10$) therefore, it was removed from the model.

Feeding behavior, aggression, gastrointestinal weights, and stress data were collected for the 2.15 and 2.45 Mcal NE/kg treatments with a stocking density of 14 or 20 pigs per pen, arranged as a factorial design. Sex was not analyzed for feeding behavior, aggression, or stress data. Data was analyzed using the MIXED procedure of SAS 9.2 (SAS Institute Inc., Cary, NC, USA) with pen as the experimental unit. The model included the fixed effects of NE and stocking density and the interaction of dietary energy and stocking density.

Injuries, lameness, and mortalities were analyzed using the PROC FREQ procedure of SAS 9.2 (SAS Institute Inc., Cary, NC, USA) and significance was determined using Fisher's exact test.

Unless otherwise indicated, all results are reported as least squares means. Probability values of $P < 0.05$ were declared as significant and $P < 0.10$ but ≥ 0.05 is discussed as a trend for both fixed effects and interactions.

2.3. Results

Pigs used in this experiment were sourced from a herd that was high health, and no signs of clinical disease were present in the barn. No effects of stocking density or dietary energy concentration on mortality, removals, lameness, or injuries were observed ($P > 0.10$; Table 2.5). Removals include all pigs that were removed from a pen due to sickness, lameness or injuries. The digestibility of GE and measured NE concentration (Mcal/kg) of diets used in this study are presented in Table 2.6.

The overall objective of this project was to examine the interaction of dietary energy concentration and stocking density in finishing pigs (75 to 118 kg). However, with the few exceptions detailed below, this interaction was not significant ($P > 0.10$) and results are therefore discussed as main effects.

2.3.1. Main effects of stocking density and dietary energy concentration

Starting weight, market weight, and CV within a pen at the start and at first pull were unaffected by stocking density or dietary energy ($P > 0.10$; Table 2.8). The first pull occurred when at least 10% of the pigs were sent to market from a room. From the time of the first pull from a room, there were three more market days (one per week) until complete room closeout.

Performance (Table 2.8)

Average daily feed intake decreased in phases 1 (75 to 90 kg BW) and 2 (90 to 105 kg BW), and the entire growth period (75 to 118 kg BW) as stocking density increased from 14 to 20 pigs per pen ($P < 0.03$), but there was no effect of stocking density on ADFI in phase 3 (105 kg to market; $P > 0.10$). As stocking density increased from 14 to 20 pigs per pen, there was an inconsistent effect on ADG, where in phases 1 and 3 there was no effect ($P > 0.10$) but in phase 2, and throughout the entire growth period, ADG was decreased ($P < 0.05$). Caloric intake in phases 1 and 2, and overall, decreased as stocking density increased from 14 to 20 pigs per pen ($P < 0.05$). However, no effect was observed in phase 3 ($P > 0.10$). There was a tendency in phase 1 for an improvement in caloric efficiency as stocking density increased ($P = 0.09$), but there were no effects of stocking density on caloric efficiency overall or in phases 2 and 3 ($P > 0.10$). Feed efficiency was unaffected by stocking density in all phases ($P > 0.10$).

Overall (75 to118 kg, BW), ADFI was decreased but caloric intake, ADG, and G:F were increased as dietary energy concentration increased ($P < 0.01$). However, caloric efficiency was unaffected ($P > 0.10$).

In phase 1 (75 to 90 kg BW), ADFI, G:F, caloric intake, and caloric efficiency increased linearly ($P \leq 0.01$), and ADG was unaffected ($P > 0.10$) when dietary energy concentration was increased. In phase 2 (90 to 105 kg, BW), ADFI decreased and ADG and G:F increased ($P \leq 0.02$) when dietary energy concentration was increased, but no changes in caloric efficiency or caloric intake were observed ($P > 0.10$). In phase 3 (105 kg to market weight), caloric intake was increased when dietary energy was increased ($P \leq 0.01$) while ADG, ADFI, G:F, and caloric efficiency were unaffected by dietary energy concentration ($P > 0.10$).

Carcass characteristics (Table 2.9)

When stocking density increased from 14 to 20 pigs per pen, 10th rib loin depth tended to increase ($P = 0.07$). There was no effect of stocking density on backfat thickness, carcass index, yield class, carcass yield, dressing percentage, or carcass weights ($P > 0.10$).

Dressing percentage and carcass weight increased linearly ($P < 0.05$) with increasing dietary energy concentration. However, backfat, loin depth, index, yield class, and carcass yield were unaffected by dietary energy concentration ($P > 0.10$).

Gastrointestinal tract and gut fill weights (Table 2.10)

The weight of the entire empty GIT from pigs raised in pens of 20 tended to be lighter than the empty GIT of pigs in pens of 14 ($P = 0.10$). Gut fill, large intestine weight, small intestine weight, and stomach weight were unaffected by stocking density ($P > 0.10$).

Empty GIT, large intestine weight, and GIT fill were unaffected ($P > 0.10$) by dietary energy concentration. However, stomach weight decreased ($P < 0.01$) and small intestine weight tended to increase ($P = 0.09$) when the high energy diet was fed.

Barn throughput and economic performance (Tables 2.11 and 2.12)

When the stocking density was increased from 14 to 20 pigs per pen, there was a linear increase in days to market, barn throughput, feed cost per pen, and annual IOFC, but calculated finisher rotations (room turns per year) were decreased ($P < 0.05$). Furthermore, as stocking density increased, there was a linear reduction in daily feed cost per pig ($P = 0.002$). There was no effect of stocking density on the carcass revenue per pig, carcass margin per pig, or feed cost per kg gained ($P > 0.10$). Increasing the stocking density in the finishing phase (75 to 118 kg BW) resulted in the greatest IOFC regardless of the market scenario modeled.

As dietary energy concentration increased from low to high, there was a linear increase in calculated finisher rotations and barn throughput($P < 0.05$), while days to market per pig tended to decrease and carcass revenues tended to increase ($P < 0.09$). Feed cost per pig, feed cost per kg gained, daily feed cost per pig and total pen feed cost increased ($P < 0.01$) with increasing energy concentration of the diet. There was no effect of dietary energy concentration on carcass margin per pig ($P > 0.10$), but there tended to be a linear improvement in annual IOFC when dietary energy concentration was increased ($P = 0.08$). When results were used in our IOFC model, the benefits of feeding a high energy diet were improved when feed costs were low or pig prices were high but when feed cost increased or pig prices decreased, the economic benefit of feeding a high energy diet was diminished.

Feeding behavior, feeder aggression, and adrenal gland weight (Table 2.13)

The number of visits to the feeder and time each pig spent at the feeder, measured over a 1 h period, was reduced when stocking density was increased from 14 to 20 pigs per pen ($P < 0.01$). There was an increase in night time feeder usage at higher stocking densities ($P < 0.05$). Feeder visits per pen, meal duration, and total time at the feeder per pen were unaffected by stocking density ($P > 0.10$).

The number of aggressive incidents per pen increased ($P = 0.02$) with increased stocking density and there was a tendency for the aggressive incidents per pig to increase ($P = 0.09$).

Displacement rate from the feeder was unaffected by stocking density ($P > 0.10$). There was no effect of stocking density on the weight of adrenal glands collected at slaughter ($P > 0.10$).

Feeder time per pig and total time at the feeder per pen, measured over a 1 h period, decreased ($P < 0.05$), and the displacement rate from the feeder after aggressive incidents measured over a 10 h period tended to decrease with increasing dietary energy concentration ($P = 0.07$). However, dietary energy concentration had no effect on feeder visits per pen, feeder visits per pig, meal duration, night time feeder usage, aggressive incidents per pen, aggressive incidents per pig, or adrenal gland weight ($P > 0.10$).

Interaction of dietary energy concentration and stocking density (data not shown)

There were no interactions between dietary energy and stocking density observed for any measured parameter ($P > 0.05$). However, in phases 1 and 3, there tended to be an interaction between dietary energy concentration and stocking density on caloric efficiency. In phase 1, the pigs in the pens of 20 that were fed the high energy diet had poorer G:F than pigs fed other energy concentrations, and in the pens with 14 or 17 pigs, dietary energy concentration had no effect on caloric efficiency (dietary energy by stocking density, $P < 0.10$). In phase 3, pigs in the pen of 14, fed the low energy diet, had a better caloric efficiency relative to the pigs in the pen of 14 that were fed the high and medium energy diet. Caloric efficiency in the pens of 17 and 20 was unaffected by dietary energy (dietary energy by stocking density, $P < 0.10$).

Table 2.5. The number of pigs used for each stocking density and dietary energy treatment and the effect of stocking density and dietary energy concentration on the removals, mortalities, injuries, and lameness in 75 to 118 kg finishing pigs[1,2]

	Stocking density			Diet regime					*P*-value[3,4]	
	Pigs per pen			Dietary NE (Mcal/kg)[5]						
Item	14	17	20	Low	Medium	High	Total	SEM	Density	NE
n, pens	18	18	18	18	18	18	54			
Pigs on treatment	266	306	360	320	306	306	932	NA	NA	NA
Removed, %	3.01	1.96	1.11	2.81	1.31	1.63	1.93	0.32	0.23	0.41
Mortality, %	1.50	1.31	0.83	1.56	0.98	0.98	1.18	0.12	0.75	0.80
Injury, %[6]	1.13	1.96	0.56	2.19	0.65	0.65	1.18	0.29	0.15	0.17
Lameness, %	1.13	1.63	0.56	1.88	0.65	0.65	1.07	0.23	0.25	0.17

[1] Data was analyzed using the PROC FREQ of SAS and significance was determined using Fisher's exact test.
[2] Arithmetic means reported.
[3] Dietary energy × stocking density ($P > 0.10$).
[4] *P*-values: Density = stocking density, NE = dietary net energy.
[5] Dietary energy concentrations formulated as; low = 2.15, medium = 2.30, high = 2.45 Mcal NE/kg. Measured levels were; low = 1.76, medium = 2.01, high = 2.204 Mcal NE/kg
[6] Injuries were counted if 1 or more of the following had occurred tail bites, lameness, lesions, and flank bite.

Table 2.6. Energy digestibility (%) and calculated net energy concentration (Mcal/kg) of the diets used in this study[1,2]

	Diet Set[3]					
Dietary energy, Mcal NE/kg[4]	1	2	3	4	n	SEM
	Gross energy digestibility					
Low	62.97	68.64	68.82	59.34	48	0.65
Medium	73.29	70.07	76.41	65.43	48	0.64
High	78.39	76.91	74.87	75.39	47	0.41
	Calculated, Mcal NE/kg[5]					
Low	1.70	1.86	1.88	1.62	48	0.02
Medium	2.04	1.97	2.15	1.86	48	0.02
High	2.24	2.23	2.16	2.18	47	0.01

[1] Celite (Celite Corp., Lompoc, CA) was added to all diets (0.4%) as source of acid-insoluble ash.
[2] Arithmetic means reported.
[3] A diet set includes all energy treatments for a phase fed to barrows or gilts.
[4] As fed basis.
[5] Dietary energy concentrations formulated as; low = 2.15, medium = 2.30, high = 2.45 Mcal NE/kg. Measured levels were; low = 1.76, medium = 2.01, high = 2.204 Mcal NE/kg

Table 2.7. Main effects of sex, stocking density, and dietary energy concentration on start weight, market weight, and coefficient of variation within a pen at the start and when the first pigs were marketed from a pen in 75 to 118 kg finishing pigs

	Sex			Stocking density			Diet regime				*P*-value[2,3,4]				
				Pigs per pen			Dietary NE (Mcal/kg)[5]				Treatment			Linear contrast	
	Male	Female	SEM	14	17	20	Low	Medium	High	SEM	Sex	Density	NE	Density	NE
n, pens	27	27		18	18	18	18	18	18						
Start wt, kg	75.3	73.9	0.9	75.1	74.6	74.0	74.4	74.5	74.8	0.9	<0.01	0.12	0.72	0.04	0.42
Market wt, kg	118.9	118.2	0.6	118.5	118.9	118.3	118.3	118.6	118.8	0.6	0.03	0.20	0.36	0.50	0.17
CV%[6]															
Start	9.45	9.17	0.64	9.36	9.62	8.96	9.52	9.11	9.32	0.67	0.43	0.30	0.64	0.35	0.41
First pull	7.74	7.47	0.38	7.54	7.84	7.42	7.49	7.77	7.55	0.41	0.37	0.52	0.87	0.74	0.45
Avg days to market	35.1	37.2	1.3	35.4	36.0	37.0	36.9	36.0	35.5	1.29	<0.01	0.03	0.06	<0.01	0.02
Days on phase 1															
Minimum	7	9		7	9	7	7	7	9						
Maximum	17	20		20	20	20	20	20	20						
Mean	12	13	0.25	12	12	13	12	12	13	0.31	0.21	0.93	0.89	0.72	0.95
Days on phase 2															
Minimum	10	9		10	10	9	9	10	10						
Maximum	18	17		15	17	18	17	18	15						
Mean	13	13	0.72	12	13	14	13	14	13	0.81	0.67	0.01	0.54	<0.01	0.67
Days on phase 3															
Minimum	14	14		14	16	14	14	16	14						
Maximum	30	23		30	23	23	28	30	23						
Mean	21	20	1.02	21	20	19	20	21	20	1.10	0.09	0.20	0.17	0.40	0.84
Days to closeout															
Minimum	37	42		37	42	37	42	44	37						
Maximum	49	49		49	49	49	49	49	49						
Mean[7]	46	46	0.93	46	46	46	46	47	45	0.96	0.59	0.62	0.12	0.98	0.37

[1] Arithmetic means reported.
[2] Dietary energy × stocking density ($P > 0.10$).
[3] Quadratic contrasts were not significant ($P > 0.10$).
[4] *P*-values: Density= stocking density, NE= dietary net energy.
[5] Dietary energy concentrations formulated as; low = 2.15, medium = 2.30, high = 2.45 Mcal NE/kg. Measured levels were; low = 1.76, medium = 2.01, high = 2.204 Mcal NE/kg.
[6] CV% = Coefficient of variation, start = d 0, first pull = 10% of pigs removed from a room.
[7] Sex × dietary energy ($P < 0.05$).

Table 2.8. The effect of stocking density and dietary energy concentration on market weight, ADG, ADFI, G:F, caloric intake, and caloric efficiency in 75 to 118 kg finishing pigs [1]

	Stocking density			Diet regime				*P*-value[2,3,4]			
	Pigs per pen			Dietary NE (Mcal/kg)[5]				Treatment		Linear Contrast	
Item	14	17	20	Low	Medium	High	SEM	Density	NE	Density	NE
n, pens	18	18	18	18	18	18					
ADFI, kg, Overall[6]	4.00	3.97	3.82	4.09	3.92	3.77	0.08	<0.01	<0.01	<0.01	<0.01
Phase 1	3.64	3.53	3.42	3.65	3.52	3.41	0.11	0.01	<0.01	<0.01	<0.01
Phase 2	4.21	4.09	3.93	4.27	4.06	3.89	0.09	0.02	<0.01	0.01	<0.01
Phase 3	4.22	4.48	4.26	4.40	4.29	4.26	0.13	0.24	0.66	0.82	0.49
ADG, kg, Overall[7]	1.21	1.21	1.17	1.17	1.21	1.23	0.03	0.05	<0.01	0.04	<0.01
Phase 1[8]	1.27	1.27	1.26	1.25	1.30	1.25	0.06	0.91	0.13	0.67	0.94
Phase 2	1.25	1.23	1.16	1.15	1.23	1.26	0.03	0.05	0.02	0.02	0.01
Phase 3	1.05	1.08	1.05	1.04	1.05	1.08	0.04	0.62	0.44	0.91	0.23
G:F, Overall[8]	0.30	0.31	0.31	0.29	0.31	0.33	0.004	0.61	<0.01	0.33	<0.01
Phase 1	0.35	0.36	0.37	0.34	0.37	0.37	0.01	0.15	0.01	0.05	0.01
Phase 2	0.31	0.31	0.30	0.28	0.31	0.33	0.01	0.63	<0.01	0.51	<0.01
Phase 3	0.25	0.24	0.25	0.24	0.25	0.26	0.01	0.69	0.18	0.76	0.07
Caloric intake, Mcal/d. Overall[7,9]	9.19	9.12	8.12	8.81	9.02	9.29	0.17	<0.01	<0.01	<0.01	<0.01
Phase 1	8.36	8.10	7.85	7.84	8.10	8.36	0.25	0.01	<0.01	<0.01	<0.01
Phase 2	9.65	9.39	9.01	9.18	9.35	9.53	0.20	0.03	0.31	0.13	0.01
Phase 3	9.70	10.30	9.76	9.46	9.80	10.50	0.30	0.24	0.03	0.87	0.01
Caloric efficiency, Gain:Mcal, Overall[9]	0.13	0.13	0.13	0.13	0.13	0.13	0.002	0.73	0.70	0.49	0.55
Phase 1[10]	0.15	0.16	0.16	0.16	0.16	0.15	0.005	0.14	0.01	0.05	0.01
Phase 2	0.13	0.13	0.13	0.13	0.13	0.14	0.004	0.66	0.24	0.55	0.12
Phase 3[10]	0.11	0.11	0.11	0.11	0.11	0.11	0.003	0.65	0.32	0.69	0.14

[1] Data presented on an as fed basis, Phases were fed from; Phase 1 (75 to 90 kg), Phase 2 (90 to 105 kg), Phase 3 (105 to market).
[2] Quadratic contrasts were not significant.
[3] Dietary energy × stocking density ($P > 0.05$).

[4] P-values and linear contrast: density = stocking density, NE = dietary net energy.
[5] Dietary energy concentrations formulated as; low = 2.15, medium = 2.30, high = 2.45 Mcal NE/kg. Measured levels were; low = 1.76, medium = 2.01, high = 2.204 Mcal NE/kg.
[6] Sex × stocking density ($P < 0.10$).
[7] Sex × dietary energy ($P < 0.05$).
[8] Sex × dietary energy ($P < 0.10$).
[9] Formulated caloric intake and efficiency are based on the formulated energy levels and not the measured values due to possible errors in the measured values.
[10] Dietary energy × stocking density ($P < 0.10$).

Table 2.9. Main effects of stocking density and dietary energy concentration on carcass characteristics, carcass yield, dressing percentage, and carcass weight in 75 to 118 kg finishing pigs

	Stocking density			Diet regime				*P*-value[1,2,3]			
	Pigs per pen			Dietary NE (Mcal/kg)[4]				Treatment		Linear Contrast	
Item	14	17	20	Low	Medium	High	SEM	Density	NE	Density	NE
n, pens	18	18	18	18	18	18					
Backfat, 10th rib , mm	18.9	19.1	18.3	18.9	19.0	18.9	0.2	0.54	0.74	0.65	0.68
Loin depth, 10th rib, mm	64.8	64.4	65.3	64.6	64.8	65.1	0.7	0.07	0.45	0.15	0.22
Index[5]	114.1	114.1	114.1	114.1	114.0	114.0	0.2	0.99	0.94	0.99	0.81
Yield class	4.5	4.6	4.5	4.5	4.5	4.6	0.1	0.33	0.55	0.47	0.52
Carcass yield, %[6]	60.6	60.5	60.7	60.6	60.6	60.6	0.1	0.31	0.79	0.47	0.84
Dressing percentage, %[7]	78.3	78.1	77.7	77.6	78.0	78.5	0.2	0.17	0.02	0.63	<0.01
Carcass wt, kg	92.7	92.3	92.3	91.7	92.6	93.0	0.6	0.40	<0.01	0.24	<0.01

[1] *P*-values and linear contrast: density = stocking density, NE = dietary net energy.
[2] Dietary energy × stocking density, sex × stocking density, and sex × dietary energy ($P > 0.10$).
[3] Quadratic contrasts ($P > 0.10$).
[4] Dietary energy concentrations formulated as; low = 2.15, medium = 2.30, high = 2.45 Mcal NE/kg. Measured levels were; low = 1.76, medium = 2.01, high = 2.204 Mcal NE/kg.
[5] Index was calculated by Thunder Creek Pork (Moose Jaw, SK) using carcass weight and carcass yield.
[6] Carcass yield was calculated by Thunder Creek Pork (Moose Jaw, SK) using back fat and loin depth measurements.
[7] Carcass wt/live wt.

Table 2.10. Main effects of stocking density and dietary energy concentration on gastrointestinal tract weights in 75 to 118 kg finishing pigs

	Stocking density		Diet regime			*P*-value[1,2]	
	Pigs per pen		Dietary NE (Mcal/kg)[3]			Treatment	
Item	14	20	Low	High	SEM	Density	NE
n, pens[4]	13	12	13	12			
Empty GIT, kg[5,6,7]	4.98	4.78	4.96	4.80	0.19	0.10	0.21
Large intestine, kg[6]	1.78	1.74	1.80	1.72	0.08	0.40	0.13
Small intestine, kg[6]	1.76	1.72	1.69	1.79	0.05	0.56	0.09
Stomach, kg[6]	0.70	0.67	0.72	0.65	0.02	0.18	<0.01
GIT fill, kg[8]	3.01	2.99	3.03	2.97	0.20	0.94	0.74

[1] *P*-values: density = stocking density, NE = dietary net energy.
[2] Dietary energy × stocking density ($P > 0.10$).
[3] Dietary energy concentrations formulated as; low = 2.15, medium = 2.30, high = 2.45 Mcal NE/kg. Measured levels were; low = 1.76, medium = 2.01, high = 2.204 Mcal NE/kg.
[4] GIT weights were collected from 2 pigs/pen.
[5] GIT = gastrointestinal tract.
[6] Cleaned and weighed empty.
[7] GIT = large intestine + small intestine + stomach + mesenteric tissue.
[8] GIT fill = GIT full wt – GIT empty wt.

Table 2.11. Main effects of stocking density and dietary energy concentration on barn throughput, carcass revenue, feed cost, feed cost margins, and annual IOFC in 75 to 118 kg finishing pigs [1]

	Stocking density			Diet regime				*P*-value[2,3,4]			
	Pigs per pen			Dietary NE (Mcal/kg)[5]				Treatment		Linear Contrast	
Item	14	17	20	Low	Medium	High	SEM	Density	NE	Density	NE
n, pens	18	18	18	18	18	18					
Days to market[6]	35.4	36.0	37.0	36.9	36.0	35.5	1.3	0.03	0.06	0.01	0.02
Calculated barn rotations[7]	3.47	3.45	3.41	3.42	3.45	3.47	0.04	0.03	0.05	0.01	0.02
Barn throughput[8]	48.5	58.6	68.3	58.0	58.5	58.9	0.7	<0.01	0.02	<0.01	<0.01
Carcass revenue/pig[9]	134.33	135.36	133.08	133.08	134.35	136.10	1.39	0.50	0.08	0.70	0.03
Feed cost/pig, CDN $[10]	30.66	30.91	30.71	29.85	30.57	31.86	1.04	0.86	<0.01	0.93	<0.01
Feed cost/kg gained, CDN $ [11,12]	0.73	0.72	0.72	0.70	0.72	0.75	0.01	0.82	<0.01	0.54	<0.01
Feed cost/pig d^{-1}, CDN $[13, 14]	0.87	0.86	0.83	0.81	0.85	0.90	0.02	<0.01	<0.01	<0.01	<0.01
Feed cost/pen, CDN $[10]	429.48	525.49	614.14	508.70	520.31	540.11	16.76	<0.01	<0.01	<0.01	<0.01
Carcass margin/pig CDN $	103.40	104.19	102.89	102.98	103.50	104.01	1.58	0.67	0.78	0.72	0.48
Annual IOFC, CDN $[14,15]	5012.50	6102.50	7015.90	5950.83	6052.26	6127.81	141.37	<0.01	0.22	<0.01	0.08

[1] Feed prices based on Saskatoon, SK 5 yr average grain prices (2009 to 2013).
[2] *P*-values and linear contrast: Density = stocking density, NE = dietary net energy.
[3] Dietary energy × stocking density ($P > 0.10$).
[4] Quadratic contrasts ($P > 0.10$).
[5] Dietary energy concentrations formulated as; low = 2.15, medium = 2.30, high = 2.45 Mcal NE/kg. Measured levels were; low = 1.76, medium = 2.01, high = 2.204 Mcal NE/kg.
[6] Days to market from 75 to 118 kg BW.
[7] Calculated finisher rotations = 365/ (days to market + (70 d constant for all treatments 20 to 75 kg BW).
[8] Barn throughput = calculated finisher rotations × pigs per/pen.
[9] Carcass revenue based on a 5 yr average Saskatchewan carcass price (2009 to 2013).
[10] Value calculated from 75 to market wt.
[11] Feed cost per kg gained = F:G × cost per tonne.
[12] Sex × energy ($P < 0.10$).
[13] Feed cost/pig d^{-1} = ADFI × cost per tonne.
[14] Sex × energy ($P < 0.05$).
[15] Annual income over feed cost (IOFC) = annual carcass revenue per pen – annual finishing feed cost per pen (75 to 118 kg BW).

Table 2.12a. The annual IOFC margins ($CDN) for pens with stocking densities ranging from 14 to 20 pigs per pen (12.96 m^2) or dietary energy treatments ranging from 2.15 to 2.45 Mcal NE/kg under different market scenarios with either feed costs or pig prices changing. Data based on the performance of finishing pigs used in the current study (75 to 118 kg BW).[1]

	Scenario of feed cost and pig prices[2]								
	Pig prices								
	Original[3]	125%	150%	-	-	75%	50%	-	-
	Feed costs								
Comparison of trts.[5]	Original[4]	-	-	125%	150%	-	-	75%	50%
High vs. low	111.88	208.05	304.21	43.69	-24.51	15.72	-80.45	180.08	248.27
High vs. medium	-18.52	30.18	78.86	-69.61	-121.70	-65.23	-112.94	34.57	86.65
Medium vs. low	129.40	178.86	226.32	113.30	97.19	80.95	32.49	145.51	161.62
20 vs. 14 pigs/pen	2,042.06	2,694.31	3,346.55	1,900.33	1,758.60	1,389.81	737.53	2,183.79	2,325.52
20 vs. 17 pigs/pen	963.16	1,264.99	1,564.83	903.12	843.07	662.33	361.49	1,023.20	1,083.25
17 vs. 14 pigs/pen	1,079.90	1,430.31	1,781.73	997.21	915.52	727.49	376.07	1,160.59	1,242.28

[1] Data reported as arithmetic means
[2] Scenarios are based on the original pig price and feed cost scenario
[3] Carcass revenue based on a 5 yr average Saskatchewan carcass price (2009 to 2013)
[4] Feed prices based on Saskatoon, SK 5 yr average grain prices (2009 to 2013).
[5] Dietary energy concentrations formulated as; low = 2.15, medium = 2.30, high = 2.45 Mcal NE/kg. Measured levels were; low = 1.76, medium = 2.01, high = 2.204 Mcal NE/kg.

Table 2.12b The annual IOFC margins ($CDN) for pens with stocking densities ranging from 14 to 20 pigs per pen (12.96 m^2) or dietary energy treatments ranging from 2.15 to 2.45 Mcal NE/kg under different market scenarios with feed costs and pig prices changing simultaneously. Data based on the performance of finishing pigs used in the current study (75 to 118 kg BW).[1]

	Scenario of feed cost and pig prices[2]								
	Pig prices								
	75%	50%	75%	50%	125%	125%	150%	150%	125%
	Feed costs								
Comparison of trts[3].	125%	125%	150%	150%	75%	50%	75%	50%	125%
High vs. low	-52.48	-149.64	-120.67	-216.84	276.24	344.44	372.41	440.60	139.85
High vs. medium	-117.32	-165.03	-169.41	-217.12	82.27	134.36	129.98	182.07	-21.90
Medium vs. low	64.84	16.38	48.73	0.28	193.97	210.07	242.43	258.53	161.76
20 vs. 14 pigs/pen	1,248.08	595.83	1,106.35	454.10	2,836.04	2,977.77	3,488.29	3,630.02	2,552.57
20 vs. 17 pigs/pen	602.28	301.45	542.24	241.41	1,324.04	1,384.08	1,625.87	1,684.91	1,203.95
17 vs. 14 pigs/pen	645.80	294.38	564.11	212.70	1,512.00	1,593.69	1,863.42	1,945.10	1,348.62

[1] Data reported as arithmetic means

[2] Scenarios are based on the original pig price and feed cost scenario

[3] Dietary energy concentrations formulated as; low = 2.15, medium = 2.30, high = 2.45 Mcal NE/kg. Measured levels were; low = 1.76, medium = 2.01, high = 2.204 Mcal NE/kg.

Table 2.13 Main effects of stocking density and dietary energy concentration on feeding behavior, feeder aggression, and adrenal gland weight in 75 to 118 kg finishing pigs [1]

	Stocking density		Diet regime			P-value[2,3]	
	Pigs per pen		Dietary NE (Mcal/kg)[4]			Treatment	
Item	14	20	Low	High	SEM	Density	NE
n, pens	7	8	8	7			
Feeder visits/h [5]	24.4	24.4	24.1	24.8	3.8	0.99	0.85
Feed visits/pig h^{-1}	1.8	1.2	1.5	1.5	0.2	0.01	0.88
Meal duration, s	228	250	270	208	64	0.64	0.23
Feeder time/pig, s[6]	369	246	340	275	31	<0.01	0.02
Total time at feeder, s	5040	4928	5537	4430	568	0.78	0.02
Nighttime usage, %	8.25	25.06	18.82	14.50	6.49	0.05	0.58
Aggressive incidents per pen/10 hr[7]	89	194	169	114	34.5	0.02	0.17
Aggressive incidents/pig	6.2	9.7	9.4	6.5	1.8	0.09	0.15
Displacement rate, % [8]	72.0	71.7	74.7	69.1	3.7	0.92	0.07
Adrenal gland weight, g[9, 10]	2.79	2.82	2.80	2.81	0.16	0.77	0.90

[1] Feeder visits and feeder bout time were recorded from 0800 to 0900 h.
[2] *P*-values: density = stocking density, NE = dietary net energy.
[3] Dietary energy × stocking density ($P > 0.10$).
[4] Dietary energy concentrations formulated as; low = 2.15, medium = 2.30, high = 2.45 Mcal NE/kg. Measured levels were; low = 1.76, medium = 2.01, high = 2.204 Mcal NE/kg.
[5] Feeder visits were defined as any feeder visit lasting longer than 20 s.
[6] Feeder time/pig = (visit/pig) × meal duration.
[7] Aggressive incidents were recorded during the 10 h light period from 0700 to 1700.
[8] Displacements rate is the percentage of pigs that pigs were removed from the feeder as a result of an aggressive interaction.
[9] Both adrenal glands were collected from each pig at the slaughter plant then weighed and averaged at a later date.
[10] The "n" used for adrenals glands: low = 25, high = 24, 14 pigs/pen = 25, and 20 pigs/pen = 24.

2.3.2. Sex

Starting ($P < 0.01$) and finishing weights ($P = 0.03$) were heavier for barrows than gilts, but within CV was unaffected by sex ($P > 0.10$; Table 2.7)

Table 2.14 displays the effect of sex on animal performance. Over all 3 phases, barrows ate more feed and consumed more calories than gilts ($P < 0.01$). Barrows grew faster in phase 1 and overall ($P \leq 0.01$) and tended to grow faster in phase 3 ($P = 0.09$) than gilts. Feed efficiency (G:F) was better in gilts than barrows overall, and in phases 2 and 3 ($P < 0.01$) but no effect of sex was observed on G:F in phase 1 ($P > 0.10$). Caloric efficiency was better in gilts than barrows in phase 1 ($P = 0.02$), 2 ($P < 0.01$) and overall ($P < 0.01$), but similar in phase 3 ($P > 0.10$).

The effects of sex on carcass characteristics, carcass yield, dressing percentage, and carcass weights are summarized in Table 2.15. Barrows had greater 10^{th} rib back fat ($P < 0.01$) but lower 10^{th} rib loin depth, carcass yield, yield class, and index relative to gilts ($P < 0.01$). Dressing percentage tended to be greater in gilts than barrows ($P = 0.10$), while carcass weights were unaffected by sex ($P > 0.10$).

Barrows had heavier stomachs ($P < 0.01$) and tended to have heavier large intestines and increased empty GIT weight compared with gilts ($P = 0.06$; Table 2.16). No differences in small intestine weight or gut fill were observed between sexes ($P > 0.10$; Table 2.16).

Table 2.17 displays the effect of sex on calculated barn throughput, carcass revenue, feed cost, carcass margin, and net returns. Barrows reached market weight sooner, had more barn rotations per year, and increased barn throughput when compared to gilts ($P < 0.01$). However, feed cost to reach market, cost per kg gained, daily feed cost and feed cost per pen were lower in gilts ($P < 0.05$). Sex had no effect on carcass value per pig, carcass margin per pig, or annual IOFC ($P > 0.10$).

Table 2.14. Main effect of sex on ADFI, ADG, G:F, caloric intake, and caloric efficiency in 75 to 118 kg finishing pigs [1,2]

Item	Sex: Barrows	Sex: Gilts	SEM	*P*-value
n, pens	27	27		
Number of pigs used	473	459		
ADFI, kg				
Overall	4.16	3.70	0.07	<0.01
Phase 1	3.67	3.38	0.11	<0.01
Phase 2	4.30	3.84	0.08	<0.01
Phase 3	4.68	3.95	0.11	<0.01
ADG, kg				
Overall	1.23	1.17	0.03	<0.01
Phase 1	1.30	1.23	0.05	0.01
Phase 2	1.23	1.19	0.02	0.20
Phase 3	1.09	1.03	0.03	0.09
G:F				
Overall	0.30	0.32	0.003	<0.01
Phase 1	0.35	0.36	0.01	0.15
Phase 2	0.30	0.32	0.01	<0.01
Phase 3	0.23	0.26	0.01	<0.01
Caloric intake, Mcal/d				
Overall	9.59	8.49	0.16	<0.01
Phase 1	8.44	7.77	0.24	<0.01
Phase 2	9.88	8.81	0.18	<0.01
Phase 3	10.77	9.07	0.25	<0.01
Caloric efficiency, Gain (kg):Mcal				
Overall	0.13	0.14	0.002	<0.01
Phase 1	0.15	0.16	0.004	0.13
Phase 2	0.13	0.14	0.004	<0.01
Phase 3	0.10	0.11	0.002	<0.01

[1] Data reported on an as fed basis.
[2] Phases were fed from; 75 – 90 kg, 90 – 105 kg, 105 – market for phases 1, 2, and 3 respectively.

Table 2.15. Main effect of sex on carcass characteristics, carcass yield, dressing percentage, and carcass weight in 75 to 118 kg finishing pigs

	Sex			
Item	Barrows	Gilts	SEM	*P*-value
n, pens	27	27		
Backfat; 10th rib, mm	19.5	18.4	0.2	<0.01
Loin depth; 10th rib, mm	64.1	65.5	0.7	<0.01
Yield class	4.8	4.3	0.1	<0.01
Carcass yield, %[1]	60.3	60.9	0.1	<0.01
Index[2]	113.5	114.6	0.2	<0.01
Dressing percentage, %[1]	77.8	78.2	0.2	0.10
Carcass wt, kg	92.4	92.5	0.5	0.70

[1] Carcass yield was calculated at Thunder Creek Pork (Moose Jaw, SK) using back fat and loin depth measurements.
[2] Index was calculated at Thunder Creek Pork (Moose Jaw, SK) using carcass weight and carcass yield.
[3] Dressing percentage = Carcass wt/live wt.

Table 2.16. Main effect of sex on gastrointestinal tract weights and gut fill at slaughter in 75 to 118 kg finishing pigs

	Sex			
Item	Barrows	Gilts	SEM	*P*-value
n, pens[1]	13	12		
Empty GIT, kg [2,3]	5.01	4.75	0.19	0.06
Large intestine, kg[3]	1.84	1.69	0.75	<0.01
Small intestine, kg[3]	1.78	1.70	0.05	0.13
Stomach, kg[3]	0.70	0.66	0.02	0.06
GIT fill, kg[4]	3.13	2.87	0.29	0.21

[1] GIT weights were collected from 2 pigs/pen.
[2] GIT = gastrointestinal tract.
[3] Cleaned and weighed empty.
[4] GIT fill = GIT full wt – GIT empty wt.

Table 2.17. Effect of sex on days to market, calculated barn rotations, barn throughput, carcass revenue, feed cost, feed cost margins, and annual IOFC in 75 to 118 kg finishing pigs [1]

	Sex			
Item	Barrows	Gilts	SEM	*P*-value
n, pens	27	27		
Days to market[3]	35.1	37.2	1.3	<0.01
Calculated barn rotations/yr [4]	3.49	3.41	0.04	<0.01
Barn throughput[5]	59.1	57.8	0.6	<0.01
Carcass revenue/pig, CDN $[2]	135.05	133.97	1.28	0.32
Feed cost/pig, CDN $[8]	31.42	30.10	1.11	<0.01
Feed cost per kg gained, CDN $[6]	0.75	0.70	0.01	<0.01
Feed cost/pig d^{-1}, CDN $[7]	0.90	0.81	0.02	<0.01
Feed cost/pen, CDN $[8]	533.29	512.79	16.48	0.02
Carcass margin/pig , CDN $	103.36	103.63	1.15	0.82
Annual IOFC, CDN $[9]	6105.16	5982.11	135.00	0.15

[1] Feed prices based on Saskatoon, SK 5 yr average grain prices (2009 to 2013).
[2] Carcass revenue based on a 5 yr average Saskatchewan carcass price (2009 to 2013).
[3] Days to market from 75 to 118 kg BW.
[4] Calculated finisher rotations = 365 / (days to market + (70 d constant for all treatments 20 to 75 kg BW).
[5] Barn throughput = calculated finisher rotations × pigs per pen.
[6] Feed cost per kg gained = F:G × cost per tonne.
[7] Feed cost/ pig d^{-1} = ADFI × cost per tonne.
[8] Value calculated from 75 to market wt.
[9] Annual income over feed cost (IOFC) = annual carcass revenue per pen – annual finishing feed cost per pen (75 to 118 kg BW).

2.3.3. Interactions

Sex by stocking density

There was a tendency for an interaction between sex and stocking density on ADFI throughout the entire growth period (75 to 118 kg BW; sex by stocking density, P = 0.08). Barrows in pens with 14 or 17 pigs per pen tended to have greater FI than the barrows in the pen of 20 while in gilts FI was unaffected by stocking density.

Sex by dietary energy concentration

Throughout the entire trial, barrows had increased ADG as dietary energy concentration was increased. However, dietary energy concentration had no effect on ADG of gilts (sex by dietary energy, P < 0.01; Fig. 2.1). In phase 1, ADG of barrows was not affected by dietary energy concentration but gilts fed the medium energy diet had a greater ADG than the gilts fed the high energy diet (sex by dietary energy, P = 0.09).

There was an interaction between sex and dietary energy on days to close out as dietary energy had no effect on this parameter in gilts but barrows fed the high energy diet had fewer days to close out compared to barrows fed the low and medium energy levels (sex by dietary energy, $P \leq 0.01$).

Throughout the entire growth period (75 to 118 kg BW) caloric intake was increased in barrows fed the high energy diet compared with the medium or low energy diets ($P < 0.05$) while gilts fed the low energy diet had a reduced caloric intake (sex by dietary energy, $P < 0.05$; Fig. 2.2).

When barrows were fed the low energy diet, barn throughput was decreased compared to barrows fed the high and medium energy diets, but there was no effect of dietary energy on the barn throughput of gilts (sex by dietary energy, $P < 0.10$). The feed cost/kg gain for barrows was unaffected by dietary energy. However, when gilts were fed the low energy diet, there was a reduction in feed cost/kg gain compared with the gilts fed the high energy diet (sex by dietary energy, $P < 0.10$). Dietary energy concentration had no effect on IOFC of gilts, but barrow IOFC was increased when they were fed the high energy diet relative to the low energy diet (sex by dietary energy, $P < 0.10$). As dietary energy increased from low to medium and medium to high, there was an increase in daily feed cost per pig for barrows. However, in gilts, the only difference was between the high and low energy diets (sex by dietary energy, $P < 0.01$; Fig. 2.3).

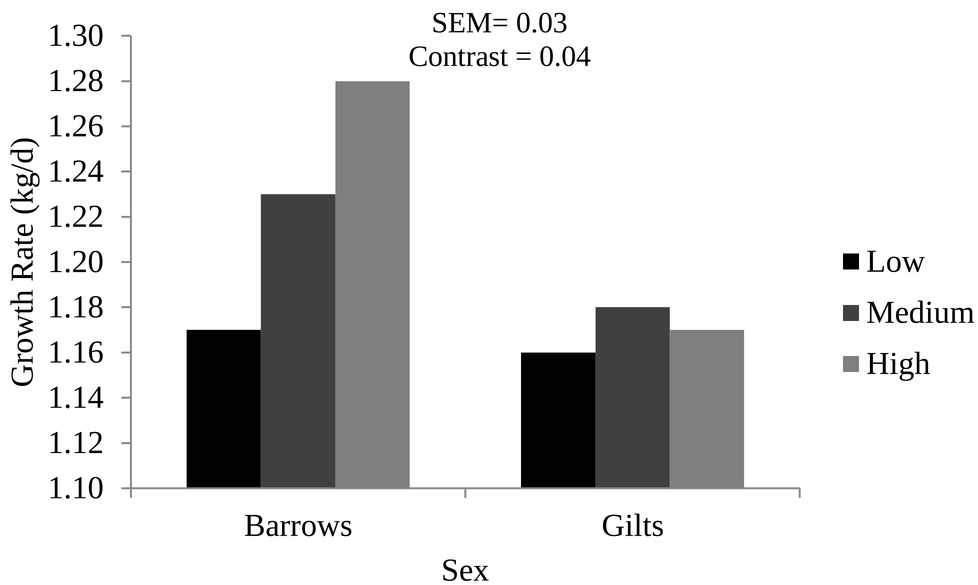

Figure 2.1. The interaction of sex and dietary energy concentration on growth in 75 to 118 kg finishing pig. Dietary energy concentrations formulated as; low = 2.15, medium = 2.30, high = 2.45 Mcal NE/kg. Measured energy levels were; low = 1.76, medium = 2.01, high = 2.204 Mcal NE/kg. Sex by dietary energy concentration ($P < 0.05$). .

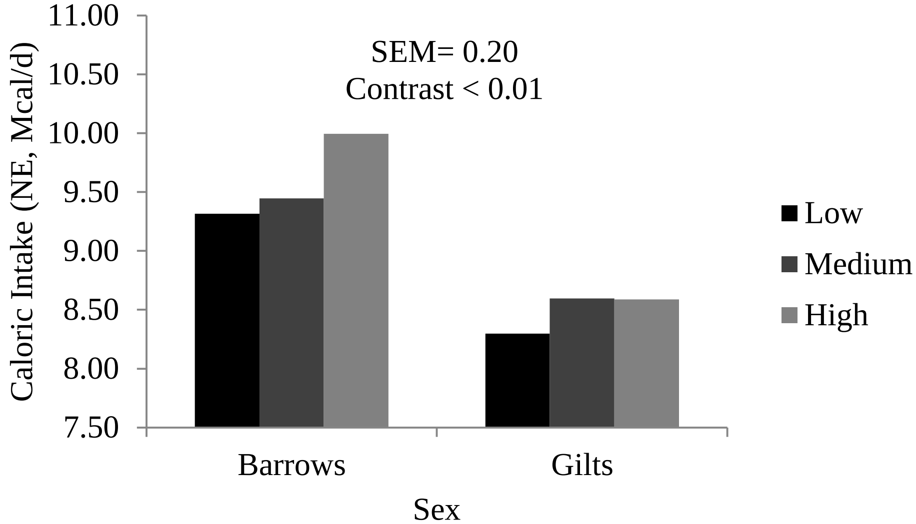

Figure 2.2 The interaction of sex and dietary energy concentration on caloric intake in 75 to 118 kg finishing pigs. Dietary energy concentrations formulated as; low = 2.15, medium = 2.30, high = 2.45 Mcal NE/kg. Measured energy levels were; low = 1.76, medium = 2.01, high = 2.204 Mcal NE/kg. Sex by dietary energy concentration ($P < 0.05$).

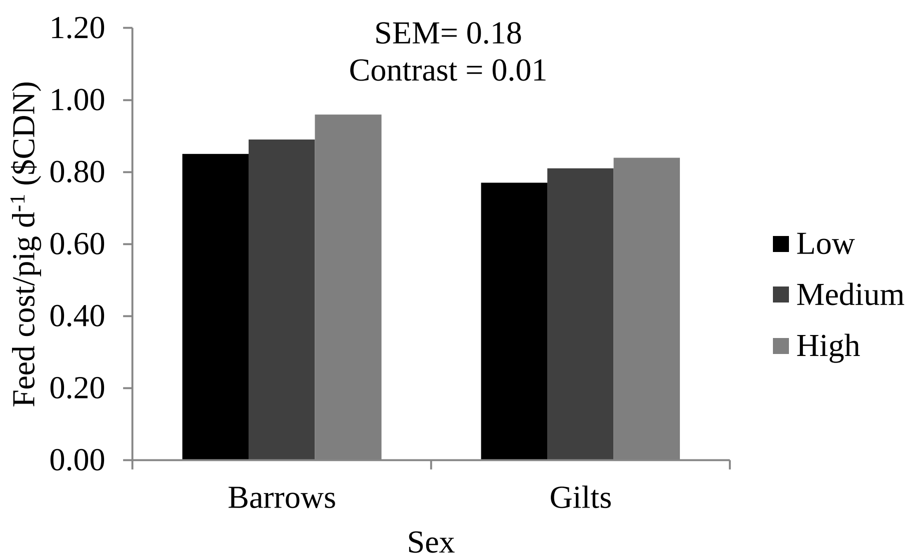

Figure 2.3 The interaction of sex and dietary energy concentration on average daily feed cost per pig in 75 to 118 kg finishing pigs. Dietary energy concentrations formulated as; low = 2.15, medium = 2.30, high = 2.45 Mcal NE/kg. Measured energy levels were; low = 1.76, medium = 2.01, high = 2.204 Mcal NE/kg. Sex by dietary energy concentration ($P < 0.05$).

2.4. Discussion

The objective of this project was to investigate the interaction between dietary energy and stocking density on IOFC for swine producers. Furthermore, we wanted to determine if pig feeding behavior was affected by either of these factors. This would provide producers with the information required to develop strategies to alleviate the negative effects of crowding or design the most cost efficient rations. Results indicated that dietary energy and stocking density affected performance and economics of growing-finishing swine, but there were no important interactions. Therefore, the main effects of dietary energy, stocking density, and sex will be discussed separately, as well as the implications of the lack of a dietary energy and stocking density interaction.

2.4.1. Pig health, productivity, and body weight variation

Pigs used in this study were pre-selected based on health and growth and were representative of the barn population. Pigs displaying signs of ill-health were not selected. Furthermore, by measuring pre-trial growth, we were assured that pigs were growing at a rate typical for their age, however, it was not necessary to excluded any pigs from this study due to pre-trial growth rate. The percentage of removals observed in this experiment was comparable to the historical barn average, but the mortality rate for this experiment was less than the rate typically observed at this facility. The pigs in this study exhibited an excellent growth rate, confirming that they were of high health and diets were adequate. The growth rate of finishing pigs (75 to 118 kg BW) in this study, surpassed that of comparable trials conducted previously at the Prairie Swine Centre (Beaulieu et al., 2009) as well as the expectations of the genetics company (Pig Improvment Company, 2013)

As intended, the variation in BW within a pen at the start of the study was similar to the typical BW variation seen in 75 kg finishing pigs in this barn. Because of this variability, some pigs were not eligible to receive phase 3 diets. Diet changes were based on the average BW of a pen, and by the time the average pen weight reached 105 kg (phase 3 start weight) the fastest growing pigs in some pens had reached market weight as was expected.

Production practices which decrease the variation within a barn have the potential to improve IOFC (Tokach, 2004). Uniform groups of pigs utilize barn space more efficiently and a greater percentage of pigs will fall within the optimum market weight resulting in fewer discounts at the slaughter facility (Tokach, 2004). It has been hypothesized that slower growing pigs will respond to increased dietary energy concentration more than their faster growing pen mates, thus reducing “tail end” pigs at the time of market and decreasing the CV of the group (Beaulieu et al., 2009). The CV, will not change if all pigs in the group have a similar improved growth rate. However, the days to closeout will decrease and barn utilization will improve (Tokach, 2004). Previous research (Beaulieu et al., 2009) showed no improvement in BW variation within a pen when dietary energy was increased from 3.12 to 3.43 Mcal of DE/kg. Beaulieu et al. (2009) did see an increase in the number of pigs that failed to reach the optimum market weight within a specified time when a low energy diet was fed. DeDecker et al. (2004) reported that increasing the stocking density reduced growth but CV was not affected. Similar to both DeDecker et al. (2004) and Beaulieu et al. (2009), we observed no effect of either stocking density or dietary energy on the variation in BW at marketing, but as pigs grew, there was a decrease in within pen CV regardless of stocking density or dietary energy treatment. This implies that in the finishing phase of production (75 to 118 kg BW), supplying pigs with more space or a greater dietary energy concentration does not improve the uniformity of pigs within a pen. However, again similar to previous work (De La Llata et al., 2001b) increasing the dietary energy did increase the growth rate and thus reduced the overall days to market and improved barn utilization.

2.4.2. Dietary energy

The control diets were formulated using a least-cost algorithm and ingredients common to Western Canada, to contain a NE concentration of 2.30 Mcal/kg. Treatment diets were formulated to contain 0.15 Mcal NE above or below this level.

Net energy concentrations of the diets were estimated in our study using the NE values for ingredients provided in the Nutrient Requirements of Swine: 11th Ed.(National Research Council, 2012). At the conclusion of the study, actual dietary NE concentration was estimated using equation 2.10 (Noblet et al., 1994 as adapted by the National Research Council, 2012) experimentally determined DE. On average, the high, medium, and low NE treatments were 10.2%, 12.6%, and 18.1% (0.25, 0.29, and 0.39 Mcal NE/kg) respectively, less than the formulated energy levels. Based on the exceptional growth and expected nutrient digestibility in this study, we believe that the measured NE levels are incorrect and are lower than the actual energy levels. There are several possible explanations for this discrepancy. The estimation equation uses a value for the maintenance requirement which was obtained from pigs kept in a different environment than the pigs used in this study (Noblet et al., 1994). Also, the pigs used to establish the equations were intact males (initial BW 35 kg) and genetically different from those used in this study. Furthermore, pigs in the current study were given ab libitum access to feed, while the equations are based on pigs that were limit fed. The differences in the environment, genetics, age, and feeding program could potentially cause differences between the actual maintenance requirements of our pigs and thus the NE. However, we also found differences between the actual and formulated DE, a value which does not depend on an estimation of maintenance. Diet digestibility values were determined using the indicator method with AIA as an external marker. Energy digestibility coefficients were approximately 10% lower than observed in a trial previously conducted at the Prairie Swine Centre (unpublished data) using pigs of similar weight and genetics and fed comparable wheat and barley based diets. Digestible energy accounts for approximately 80% of GE, and the NE accounts for 70% of the DE content (Noblet et al., 1994). An error in the determination of DE would have a large effect on calculated NE. In the current study, the ratio of AIA in feed and feces was 0.27 while in the previous work, using a similar diet, this ratio was 0.17. We recognize that these ratios will change but suspect that the differences in this experiment were caused by low fecal AIA values observed in the current study, suggesting that a portion of the AIA in the feed was not excreted in the feces. Feeding mash feeds could have allowed for greater sorting and feed wastage (Schell et al., 2001) and the wet dry feeders used could allow for further separation of the AIA particles from the diet prior to ingestion. We propose that the use of mash diets and wet dry feeders allowed for a portion of the AIA content of the diet to be sorted prior to ingestion and the method used under estimated the true energy content of the feed.

Dietary energy effects on performance

In general, if pigs fed varying dietary energies are able to maintain comparable caloric intakes and efficiencies, growth rate is unaffected. The Pig Improvement Company (PIC) reports that under conditions of optimum health and environment, growing-finishing pigs (60 to 122 kg BW) of their genetics will grow about 1.0 kg/d (Pig Improvment Company, 2013). The pigs used in the current study were PIC genetics and thus their growth rate (1.20 kg/d) was exceptional both for their genetics and when compared to other reported studies (Apple et al., 2004; Weber et al., 2006; Beaulieu et al., 2009; Hinson et al., 2011; Quiniou and Noblet, 2012). Gilts were able to maintain a similar growth rate across dietary energies but had slower growth rates than barrows (1.17 vs. 1.23 kg/d). A slower growth rate and an improved caloric efficiency led to a reduced caloric requirement for gilts to achieve maximum growth rate. The increased growth rate and poorer caloric efficiency increased the caloric requirement for maximum growth for barrows, requiring a greater adjustment in FI in order to maintain a consistent caloric intake when dietary energy was decreased

A review of the literature indicates that as the concentration of energy in the diet is decreased, FI will increase and G:F will be reduced. Growth will decline if caloric intake is not maintained and the efficiency of utilization of energy remains comparable to that of high energy diets (Brumm and Miller, 1996; Smith et al., 1999; De La Llata et al., 2001a; Beaulieu et al., 2009; Hinson et al., 2011; Quiniou and Noblet, 2012). In the current study, gilts increased FI by 9.9% when dietary energy was decreased from 2.45 to 2.15 Mcal NE/kg (formulated NE levels) but, this was not sufficient to maintain caloric intake. Growth rate, however, was comparable between the low and high energy diets. Caloric efficiency (kg gained/Mcal NE) was numerically increased when dietary energy was decreased but this was not statistically significant. Gilts fed the low energy diet were able to consume and utilize sufficient calories to maintain a growth rate consistent with the medium and high energy diets. Smith et al. (1999) and De La Llata et al. (2001a) reported consistent energy intakes in growing finishing pigs when dietary energy content varied from 3.3 to 3.6 Mcal ME/kg. Furthermore, Smith et al. (1999), as well as a second trial reported by De La Llata et al. (2001a), reported no difference in growth when pigs were fed diets with increased energy concentration. In his first trial, De La Llata et al. (2001a) reported similar caloric intakes but a decrease in caloric efficiency and reduced growth when dietary energy was decreased. Beaulieu et al. (2009) also reported that in the second trial of her experiment, finishing pigs (80 to 120 kg BW) increased FI to maintain a constant caloric intake with no effect on growth when dietary energy was decreased from 3.50 to 3.20 Mcal DE/kg. If caloric intake is maintained when dietary energy is decreased and efficiency of utilization of that energy is similar, then growth will be unaffected (Smith et al., 1999; De La Llata et al., 2001a; Beaulieu et al., 2009).

Contrary to her second trial which was conducted in a commercial barn, Beaulieu et al. (2009) reported in her first trial (conducted in a research facility) that FI increased but not enough to maintain caloric intake or growth which decreased when dietary energy was decreased from 3.61 to 3.05 Mcal DE/kg. The barrows in the current study increased FI by 6.75% when dietary energy concentration was decreased from 2.45 to 2.15 Mcal NE/kg, but the increase in FI was not sufficient to maintain caloric intake and caloric intake decreased by 7.3% and growth was reduced by 8.6% (75 to 118 kg BW). Quiniou and Noblet (2012) reported that when pigs (36 to 109 kg BW) were fed 6 diets ranging from 1.94 to 2.65 Mcal NE/kg, as dietary energy increased there was a linear increase in caloric intake, resulting in a linear increase in growth. Hinson et al. (2011) reported that finishing pigs (100 to 123 kg BW) reduced FI and caloric intake when dietary energy concentration was decreased from 3.54 to 3.32 ME Mcal/kg resulting in a 0.25 kg/d reduction in growth when dietary energy was decreased. If caloric intakes are not maintained when dietary energy concentration is decreased, then growth will decrease (Beaulieu et al., 2009; Hinson et al., 2011; Quiniou and Noblet, 2012). In summary, as dietary energy is varied, the ability for pigs to exhibit a constant growth rate is dependent on whether pigs adjust FI to compensate for the change in caloric density and on the utilization of those calories (Smith et al., 1999; De La Llata et al., 2001a; Beaulieu et al., 2009; Hinson et al., 2011; Quiniou and Noblet, 2012).

Carcass characteristics

Previous research conducted by Beaulieu et al. (2009), Quiniou and Noblet (2012), and Asmus et al. (2014) reported that dressing percentage (kg carcass wt /kg live wt) improved when dietary energy was increased. In agreement with these studies, the current study found that even though market weight was unaffected, increasing dietary energy increased carcass weight by 1.22 kg and improved dressing percentage by 0.81%. In our study, final live BW was measured prior to a 16 h fast before being slaughter. An increased FI in the low energy treatment may have resulted in increased gut fill when final weights were taken resulting in the reduced dressing percentage. Kyriazakis and Emmans (1995) and Whittemore et al. (2003), both showed that gut fill increased when pigs were fed low energy diets, which would be noticed if pigs were slaughtered without a fasting period. We hypothesize that the primary cause for the reduced dressing percentage in pigs fed the low energy diets was the increase in gut fill, resulting from the increased fiber content of this diet. The gut fills reported in this study are post fasting, and do not represent the gut fill at final live weight which was used to determine dressing percentage. As dietary energy increased, there was an increase in empty small intestine weights and a decrease in stomach weight, resulting in empty GIT weight being unaffected by dietary energy. Furthermore, we saw no increase in gut fill measured at the slaughter facility (post-fasting period). Quiniou and Noblet (2012) reported that differences in dressing percentages were a result of using live pre-fasting BW for the calculation of dressing percentage. Likewise, we suspect that if final live weights had been obtained post fasting in our experiment, the dressing percentage would not have been affected by dietary energy concentration

Previous research has shown that as dietary energy increases there is an increase in energy intake and 10^{th} rib backfat (Hinson et al., 2012, Quiniou and Noblet 2012). Furthermore, Weber et al. (2006) showed an increase in 10^{th} rib loin depth and backfat when dietary energy was increased. In the current experiment, despite increased caloric intake by pigs fed the high energy diet, longissimus muscle depth and 10^{th} rib backfat were unaffected by dietary energy. However, we did see an increase in growth when pigs were fed a higher energy diet, suggesting that pigs were using the excess calories for lean growth and had not yet reached their maximum lean growth potential. The lack of a measured tissue deposition response could happen if excess calories were used for lean tissue deposition in other parts of the body or the duration of higher caloric intake was not sufficient for a difference in backfat or loin depth between dietary energies to be detected.

Economics

As dietary energy concentration increased from low to high, there was a 20% increase in diet cost per tonne (based on 5 yr average ingredient costs) but because of the decreased intake of the high energy diets, daily feed cost/pig increased by only 9%. Furthermore, because of the reduction in days to market, the overall cost of feed for a pig to grow from 75 to 118 kg for the pigs fed the high energy diet was only 6.7% greater than the low energy diet. Pigs fed the high energy diet had increased carcass weights and thus increased carcass revenue. The increase in revenue and the reduction in days to market compensated for the increased feed cost, and there was no difference in the carcass margin per pig. When calculated on a yearly basis, increasing the dietary energy from low to high increased barn throughput by 1.5%, and improved IOFC by 3.0%.

The incentive for feeding a high energy diet is the increase in barn throughput and carcass value. Similar to our findings, De La Llata et al. (2001b) reported an increased IOFC when dietary energy was increased. Conversely, Beaulieu et al. (2009) found that increasing dietary energy did not improve IOFC and that the IOFC favored feeding a low energy diet. The different results between Beaulieu et al. (2009) and the current study are probably due to different pricing scenarios, marketing grids, and pig performance. Because of the volatility in the feed and pork markets, optimal dietary energy concentration is not constant. Failing to adjust dietary energy levels to the optimum level may result in economic losses. Thus, to maximize returns, a specific optimal dietary energy must be determined on a farm by farm basis using current market prices that are applicable to the specific situation. Based on the data from the current experiment, we determined that as carcass prices increase or diet costs decrease, the margin in IOFC between the high and low energy diets increases. When diet costs increase or carcass prices decrease, the IOFC margin between the low and high energy begins to decrease and a 28% increase in diet cost or 29% decrease in carcass value would result in the low energy diet having a higher IOFC than the high energy diet. In the midst of increased diet cost or reduced carcass prices, the medium dietary energy remains the best option until the diet costs are increased to 300% of the original diet costs, at which point the low energy would become the most economical.

Feeding behavior

Decreased dietary energy typically requires a lower fat content, as well as also increased dietary fiber. Kallabis and Kaufmann (2012) investigated the effect of dietary fiber content on grower-finisher pig feeding behavior. By increasing the dietary fiber, Kallabis and Kaufmann (2012) decreased the dietary energy concentration of the diet. In the finishing stage (80 to 125 kg BW) of their trial, feeder visits were unaffected by dietary energy, but overall time at the feeder and meal duration increased when dietary energy concentration was increased. In agreement, we saw an increase in FI and a reduction in G:F as dietary energy concentration was decreased, and our results also show that pigs fed the low energy diet spent more time at the feeder. Feeders were occupied 77% of the time when the low energy diet was fed compared with just 62% when the high energy diet was fed. However, the incidence of injuries and aggression at the feeder was unaffected by dietary energy. This suggests that there was adequate feeder space provided in this study. Furthermore, Gonyou (1999) estimated that if pigs occupied the feeder for less than 80% of the time, then feeder space was adequate, suggesting that FI in the current study was restricted by something other than lack of available feeder access. Increased feeder usage, combined with the increase in FI, indicates that pigs receiving the low energy diet were adjusting to the diet and attempting to maintain caloric intake comparable to the high energy diet. However, caloric intake was decreased on the low energy diet. Pigs fed the low energy diet may have become satiated due to a full GIT prior to reaching a caloric intake comparable to those receiving a diet with a higher energy.

Kyriazakis and Emmans (1995) and Whittemore et al. (2003) reported that pigs will adjust to lower energy feeds (fibrous) with increased stomach, large intestine, and cecum weights and that as the weight of the GIT increases, the capacity of the GIT also increases. In the current study, small intestine weights increased when pigs dietary energy was increased, however, we do not know why this increase occurred. On the contrary, stomach weights increased when pigs were fed a low energy diet. Gut capacity is the capacity of the gut at a given point in time and based on a prediction equation for gut fill capacity; (kg) = $0.277 \times BW^{0.612}$ (De Lange et al., 2003), the gut capacities for pigs in the current study were 4.12, 4.57 and 4.95 kg. However, the FI for the entire day for low energy diets was 3.65, 4.27, 4.40 kg/d for phases 1, 2, and 3 respectively. This suggests that gut capacity did not restrict FI. However, many different factors such as feed bulk and fiber level influence gut capacity and more effort is required to characterize these in order to accurately predict gut capacity in different situations. Furthermore, we were unable to measure gut fill pre-fasting period, but the increases in feeder usage and stomach weights would suggest that pigs were adapting to the low energy treatment. However, they were unable to adjust FI to a point where caloric intake was comparable with the high energy diet.

2.4.3. Space allowance

In this experiment, space allowance and group size changed simultaneously and thus the two are confounded. Increasing group size makes it more difficult to establish a social hierarchy, resulting in increased aggression (Ewbank, 1976). However, Schmolke et al. (2003, 2004), observed the social behavior of pigs in pens of 10 to 80 and concluded that with these populations, there was no effect of group size on aggression, welfare, injuries, or performance when adequate space was supplied. Similar results were reported by Randolph et al. (1981), Kornegay and Notter (1984), and Wolter et al. (2001). In the current study, group size only differed by a maximum of 6 pigs per pen and therefore, the reduction in animal performance and changes in feeding behavior that occurred when stocking density was increased can be attributed to decreased space allowance.

According to the recent Canadian Code of Practice for the Care and Handling of Pigs (National Farm Animal Care Council, 2014) grow-finish pigs should be allowed sufficient space to provide a *k*-value greater than 0.0335. A *k*-value defines space allowance independent of BW. In the current study, pigs marketed at 118 kg BW in the pen of 14 never reached this value. However, 56% of the pens with 17 pigs and all of the pens of 20 pigs reached this value prior to marketing. Unlike the pens of 14 and 17, all of the pens of 20 were considered crowded and reached a crowded *k*-value ($k < 0.0335$) within an average of 12 d after trial initiation and were therefore housed in a crowded environment for 19 d. At least 4 pigs needed to be removed from the pen of 20 on the first pull to relieve crowding. When less than 4 were removed, the pen was again crowded by the next weigh day one week later. This was the case for some of the pens of 20. However, no pens were crowded after the second week of market removals.

Performance

In the current study, performance of pigs was comparable between the 14 and 17 pigs per pen treatments, probably because of minimal crowding in these pens (based on the *k*-value criteria $k < 0.0335$; National Farm Animal Care Council, 2014). However, comparable with what has been shown by others (Gehlbach et al., 1966; Brumm and Miller, 1996; Edmonds et al., 1998; Gonyou and Stricklin, 1998; Brumm et al., 2001; Brumm, 2004; Brumm et al., 2004; DeDecker et al., 2005; Anil et al., 2007; Potter et al., 2010), increased stocking density was associated with reduced feed and caloric intake and growth. There was a 6.4% reduction in ADG after the onset of crowding in the pen of 20 pigs. Regardless of the cause, crowded pigs were unable to consume sufficient calories to meet the demands for maximum growth.

Economic performance

Results indicate that on a per pig basis, pigs in the pen of 20 had the lowest feed cost per day, but required 1.6 more days to reach market weight (118 kg BW) resulting in no difference in total feed cost to reach market weight. Furthermore, there were no differences in carcass value due to stocking density, and therefore, IOFC per pig was unaffected by stocking density. Potter et al. (2010) reported that in pens of 22 to 28 pigs, a pen with 24 pigs had the highest IOFC per pig placed, while the pen of 28 had the highest IOFC on a pen basis. In our study, barn throughput was increased by 17% when stocking density increased from 17 to 20 pigs per pen and by 40% when stocking density was increased from 14 to 20 pigs per pen. Because of the increase in barn throughput and the lack of a difference in IOFC per pig, stocking density was the most important factor determining annual IOFC. As stocking density increased, there was a linear improvement in IOFC on a per pen basis. This suggests that the negative effect of crowding on pig performance did not diminish the improvement in barn throughput.

After modelling net returns in 2000 head finisher barn, Brumm (2008) found that increasing the stocking density from 25 to 27 pigs per pen would increase the barn throughput and increase net returns even with reduced growth. Based on the results of our study, we determined the effect of different market scenarios on the IOFC, and even under the most extreme scenario (230% increase in feed cost and 50% reduction in carcass value) the pen of 20 still had the highest IOFC. In conclusion, only if growth was reduced or mortalities were increased such that barn throughput was adversely affected would it would no longer be profitable to increase stocking density.

Feeding behavior

Pigs alter their feeding behavior when they are crowded (Hyun et al., 1998; Gonyou, 2001; Street and Gonyou, 2008). Street and Gonyou (2008) reported that crowded finishing pigs (95 kg BW) ate fewer meals and spent less time at the feeder each day, yet overall FI was unaffected. Hyun et al. (1998) reported similar results in that, as space allowance was decreased, pigs had fewer feeder visits and FI was unchanged. Hyun et al. (1998) also reported that crowded pigs had similar total daily feeder occupation time, had longer feeder visit durations and consumed more feed at each visit compared with uncrowded pigs. In agreement with Street and Gonyou (2008), decreasing the space allowance in the current experiment resulted in pigs making fewer visits to the feeder and spending 33% less time at the feeder. Unlike Hyun et al. (1998) and Street and Gonyou (2008), we observed a 5% reduction in FI. Hyun et al. (2008) used a non-competitive feeding environment where pigs were protected from displacement, while the pigs in our study were in a competitive feeding system. In our study, the number of feeder visits per pen and overall time at the feeder were similar regardless of stocking density, but pigs decreased the number of visits and time spent at the feeder during the daytime period.

Changing the feeding pattern allows the crowded pigs to maintain a caloric intake similar to that of the uncrowded treatment. The current study measured nighttime feeder usage and pigs in the crowded pens responded to the reduction in time spent at the feeder during the day by increasing feeder usage at night by 17%. However, this was not sufficient to increase caloric intake to an amount equal to that in uncrowded pens.

Changes in feeding behavior and pattern when pigs are crowded may be partially caused by an increase in aggression at the feeder. Research has consistently reported increased aggression among pen mates as space allowance decreases (Ewbank and Bryant, 1972; Randolph et al., 1981; Anil et al., 2007) and in the current study we saw an increase in the number of aggressive disruptions at the feeder with decreased space allowance. Ewbank and Bryant (1962) reported that the approach of a dominant pig or a brief aggressive interaction will cause the less dominant animal to submit and leave the feeder. Our results suggest that as aggression increased, pigs made fewer daytime feeder visits and spent less time at the feeder (daytime), forcing them to change their typical feeding pattern and adopt a nocturnal feeding pattern.

The reduction in caloric intake caused by increased stocking density contributed to a reduction in growth. The reduced caloric intake may be due to the increase in aggression as discussed above, but others have hypothesized that crowding reduces growth directly by decreasing the pig's ability to exhibit their maximum growth potential. Lean growth potential is the maximum lean growth rate that a pig can achieve, and Chapple (1993) postulated that the stress due to crowding decreases the pig's ability to exhibit their maximum lean growth potential. In general, growth is accomplished with the nutrients that are not used for maintenance requirements. When pigs become stressed, the hypothalamic pituitary axis is activated and glucocorticoids are released (Matteri et al., 2000). The release of glucocorticoids, such as cortisol, can result in increased serum leptin that in turn decreases appetite and FI (Matteri et al., 2000). Furthermore, when animals experience acute or chronic stress, the basal metabolic demands are increased and the nutrients available for growth are decreased (Elasser et al., 2000). The decrease in appetite, combined with the change in nutrient partitioning, could lead to a reduction in the energy available for growth.

The results of our study do not provide a clear answer for the cause of the reduced caloric intake when pigs are crowded. It may be caused by either a restriction in caloric intake or secondary to a reduction in the pig's ability to exhibit maximum growth rate due to stress. There is evidence leading us to hypothesize that crowded pigs had reduced growth due to restricted feeder access. First, the altered feeding pattern of crowded pigs would suggest that pigs were making an effort to consume the calories required to sustain their maximum growth rate. Furthermore, a stressed animal secretes a greater amount of cortisol, which is produced in the adrenal gland (Freedman, 1975). An increase in adrenal glands weights would suggest that the crowded pigs produced and secreted greater amounts of cortisol due to chronic stress, but we saw no increase in adrenal gland weights. Finally, throughout the entire growth period (75 to 118 kg BW), caloric efficiency, carcass fat, and carcass lean were unaffected by stocking density, indicating that calories were not required or used for a stress response but crowded pigs used calories similarly to the uncrowded pigs. Moreover, as discussed later, increasing the dietary energy did not alleviate the negative effects of crowding on growth, even though there was an increase in caloric intake when the high energy diet was fed. This leads us to hypothesize that the negative effects of crowding were caused by a reduction in the pigs ability to express its maximum growth potential.

2.4.4. Sex

Barrows (60 to 120 kg BW) grow faster, but have a poorer G:F compared with gilts of a comparable BW (Coffey et al., 2000; Lewis and Southern, 2000; Brumm, 2004). Our results were similar to Coffey et al. (2000) and Brumm et al. (2004), who also fed diets formulated to meet the unique requirements of each sex. In their experiment, gilts had a lower FI, improved G:F, lower caloric intake, better caloric efficiency, and increased carcass lean compared with barrows. The difference in G:F can partially be attributed to decreased lipid and increased protein deposition at comparable bodyweights (Quiniou et al., 1999; Lewis and Southern, 2000). Because of this, barrows and gilts of the same age have different nutrient requirements and thus separate diets must be formulated. The feeding programs used in this experiment ensured that pigs were supplied a diet that would meet or exceed, (but not excessively) the nutrient requirements established by the National Research Council, (2012). If barrows and gilts had been fed the same diets when at similar BW, one of the sexes would be under or over fed nutrients and the effect of dietary energy or stocking density could not be properly assessed. Excess nutrients increase diet costs, do not yield improved performance, and may even decrease the NE content of the diet. Formulating diets to meet the precise nutritional requirements of the pig increases utilization of nutrients for growth and improves net returns (Cromwell, 1994; De Lange et al., 1994).

Gilts had increased days to market and reduced annual barn throughput. However, the feed cost for gilts to reach market weight and cost per kg gain was lower and therefore there was no difference in IOFC. If considering only the finishing phase of growth (75 to 118 kg BW), there was no advantage in IOFC to finishing either barrows or gilts.

2.4.5. Interaction between dietary energy and stocking density

The overall objective of this experiment was to determine if increasing dietary energy would allow for increased nutrient intake and mitigate the negative effects of crowding on growth. In previous studies, using both growing and finishing pigs, supplying additional nutrients did not alleviate the negative effects of crowding in finishing pigs (Kornegay et al., 1993; NRC-42 Committee on Swine Nutrition, 1993; Brumm and Miller, 1996; Edmonds et al., 1998). In the current study, increasing dietary energy concentration improved growth performance. However, there was no interaction between dietary energy and crowding on either performance or economic returns. Similarly, studies by NRC-42 Committee on Swine Nutrition (1993) and Brumm and Miller (1996) using diets formulated with the addition of fat, lysine, or fat and lysine also showed no interaction between space allowance and nutrient supplementation. Brumm and Miller (1996) examined the interaction between energy and space allowance in 22 to 107 kg pigs that became crowded at 68 kg BW. The diets in their study were corn based and thus the energy levels were higher than used in the current study. Caloric intake did not respond to changing space allowance and there was a reduction in growth and lean gain with decreasing space allowance (Brumm and Miller, 1996). Furthermore caloric intake was unaffected by changing dietary energy concentration and growth was improved with increasing dietary energy caused by increased caloric efficiency of pigs fed the high energy diet. However, increasing dietary energy concentration did not improve the growth rate in the crowded pen. The lack of a caloric intake response and change in growth when dietary energy and space allowance were increased, suggests that pigs were using calories for a stress response or that pigs were unable to express their maximum growth potential. In our study, as space allowance was decreased there was a linear reduction in caloric intake and growth, leading to the hypothesis that if pigs were able to maintain a comparable caloric intake at higher stocking densities, growth would be unaffected and conversely, the restriction in nutrient intake caused the reduction in growth. However, offering pigs in the pens of 20 a diet with increased dietary energy concentration increased caloric intake, but not enough to increase growth. This suggests that regardless of caloric intake, the expression of growth potential in crowded pigs was reduced. Aggression at the feeder was increased when stocking density was increased, indicating that pigs in the crowded pen encountered more stressful situations. There are several factors that could explain why the pigs in our trial responded differently to increased stocking density than those in Brumm and Miller (1996). The dietary energy concentration in our experiment ranged from 2.95 to 3.24 Mcal ME/kg while Brumm and Miller (1996) used a series of diets with the lowest energy content of 3.28 Mcal ME/kg which would make it easier for pigs to maintain a comparable caloric intake across stocking densities. Furthermore, in their work, pigs were crowded for a longer duration and were on trial from 22 to 107 kg BW, allowing pigs to adjust FI to sustain growth (Brumm and Miller, 1996). Regardless, in agreement with the current experiment, they also reported no interaction between stocking density and dietary energy. The lack of an interaction in the current study is due to a similar performance response to dietary energy across all stocking densities, and the negative effects of high stocking density on performance were not mitigated by dietary energy. Thus, we propose that the decrease in growth observed in crowded pens was not caused by a restriction in feeder access but the ability for pigs to exhibit their maximum growth potential is decreased, but the specific mode of action still remains to be elucidated.

Although there were no significant interactions for the economic variables, numerical differences were observed which provides insight into an optimal dietary energy for maximized returns on investments. The greatest IOFC was observed in the pen with 20 pigs. Within the pen of 20, feeding the medium energy diet resulted in numerically increased IOFC, but only $70.00

(CDN) per pen/yr higher than when these pens received a high energy diet. When pigs in the pen of 20 were fed the low energy diet, the IOFC was $100.00 dollars lower than the pigs fed the high energy diet. Conversely in the pens of 14, there was no improvement in IOFC when dietary energy was increased as all pens had an IOFC within $40.00 of each other. In summary, when stocking density was decreased to 14 pigs per pen, there was no benefit to increasing dietary energy. However, as stocking density increased, increasing the dietary energy numerically improved the IOFC. Contrary to previous work (Beaulieu et al., 2009), providing a high energy diet in our study did not decrease IOFC and providing the high energy diet was the best option to increase IOFC in this study. In favorable markets where feed costs are low or hog value is increased or both, it may be more beneficial to feed a high energy diet to pigs in high stocking density. In markets where feed costs are increased or carcass values are decreased or both, it would still be economically beneficial to increase the stocking density, while the optimal dietary energy may decrease.

3. Conclusions and implications

In this experiment, increasing the stocking density to the point of crowding in the late finishing phase (*k*-value < 0.0335 at 85 kg BW) reduced FI and growth but increased barn throughput and was the most profitable option. From a welfare perspective, crowding in the late finishing phase (85 kg BW) did not compromise the health, mortality, or morbidity of pigs in these pens which had an established hierarchy. Within reasonable fluctuations of feed and pig prices (50% increase in feed cost and 50% decrease in pig prices), the highest stocking density was the most profitable option. However, if pig prices were to decrease by 50% and feed cost increased to $500.00 per tonne ($CDN; 230% of the original diet cost) the pen of 14 would become the most profitable stocking density.

Feeding a high energy diet resulted in an improved growth rate and G:F while also being the diet providing the greatest IOFC. Furthermore, the economic benefits of feeding a high energy diet are improved when feed costs are low or pig prices are high but with the opposite scenario, an increase in feed costs or a decrease in pig prices, the economic benefit of feeding a high energy diet is lessened. When modeling the result from this experiment, the low energy diet will eventually become more profitable than the high energy diet, but because of the reduction in barn throughput and reduced performance, the low energy diet would require a 300% increase in feed cost from that used in our model (2008 to 2013 average) to surpass the profitability of the medium energy diet. When diet cost decrease or pig prices increase or both, profitability increasingly favors pigs that have an improved growth rate and G:F. However, when pig prices decrease or diet costs increase, it is more profitable to feed a dietary energy concentration that results in a moderate growth rate and G:F, based on an economic model developed from the results of this experiment.

In conclusion, dietary energy and stocking density independently affected pig performance, behavior, and economic returns. The addition of dietary energy to crowded pens increased caloric intake but not growth. We agree with the hypothesis that crowding decreases the ability for pigs to express their maximum growth potential, but the mechanism through which this occurs remains to be studied.

The most profitable stocking density was the pen of 20 pigs, thus packers, grocers, and consumers must be willing to pay more for pork from pigs housed at lower stocking densities or net returns will decrease. In conclusion, the dietary energy which maximized IOFC did not depend on stocking density. Furthermore, dietary energy and stocking density independently affect net returns, pig performance, feeding behavior, and aggression.

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A. Appendix A

Table A.1. The weight at which finishing pigs housed on fully slatted floors become crowded

Pigs per pen[1]	BW at crowding (kg)[2]
14	145
15	131
16	119
17	108
18	100
19	92
20	85

[1] Pen area=12.96 m^2.
[2] Crowding was defined as a *k*-value of 0.0335.

Table A.2. Five year average grain prices and micro-ingredient prices used to determine the cost of the diets used in this experiment

Ingredient	Cost per tonne, CDN $
Grains	
Barley [1]	$ 181.83
Wheat [1]	$ 210.29
Millrun wheat[1]	$ 173.00
Peas[1]	$ 227.20
Oat hulls [1]	$ 65.00
Canola meal[1]	$ 263.65
Micro- ingredients	
Limestone	$ 145.00
Tallow[1]	$ 907.35
Salt	$ 300.00
Vitamin premix	$ 4,400.00
Mineral premix	$ 3,120.00
Ronozyme NP CT	$ 6,000.00
L-Tryptophan 98%	$65,000.00
Celite	
Lysine HCL 78%,[1]	$ 2,307.42
L-Threonine 98% [1]	$ 2,855.50
Choline chloride	$ 1,950.00
DL-Methionine 98%	$ 5,100.00

[1]Five year average price used

Table A.3. Monthly average finishing pig carcass prices (CDN$) per 100 kg for Saskatchewan from 2009-2013

	Month												
Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
2013	151.72	154.68	139.54	147.95	164.38	183.06	189.18	183.90	174.51	168.25	156.18	151.39	163.73
2012	154.67	156.78	154.11	146.92	146.74	175.02	178.16	161.21	125.89	144.29	142.53	146.27	152.71
2011	132.79	146.95	147.38	158.42	160.20	166.76	165.89	182.51	158.91	170.07	156.92	152.95	158.31
2010	125.61	126.44	130.61	143.85	157.45	145.62	146.89	154.05	121.48	125.15	112.12	124.37	134.47
2009	129.33	128.73	132.46	129.43	122.50	117.72	117.45	94.78	98.78	97.13	102.58	117.44	115.69
5 Yr Avg	138.82	142.71	140.82	145.31	150.25	157.63	159.51	155.29	135.92	140.98	134.07	138.48	144.98

Table A.4 Marketing grid for pigs delivered to Thunder Creek Pork (Moose Jaw, SK) from November 2012 to June 2013

	Weight range, kg											
	0.00	65.00	70.00	75.00	80.00	85.00	90.00	95.00	100.00	105.00	110.00	115.00
	64.99	69.99	74.99	79.99	84.99	89.99	94.99	99.99	104.99	109.99	114.99	and up
Lean yield, %												
64.3 and up	10	10	50	75	106	109	109	109	107	102	100	50
63.0 - 64.3	10	10	50	75	109	113	113	113	111	107	100	50
61.8 - 63.0	10	10	50	75	111	116	116	116	113	108	100	50
60.7 - 61.8	10	10	50	75	109	116	116	116	113	107	100	50
59.6 - 60.7	10	10	50	75	106	114	114	114	111	106	100	50
58.6 - 59.6	10	10	50	75	104	110	110	110	107	106	95	50
57.7 - 58.6	10	10	50	75	100	110	107	107	104	101	90	50
56.9 - 57.7	10	10	50	60	90	110	103	103	95	90	80	50
56.2- 56.9	10	10	50	60	90	110	95	95	90	80	70	50
56.1 and down	10	10	50	60	70	110	70	70	70	60	60	50

Table A.5. The effect of sex, stocking density, and dietary energy concentration on caloric intake and caloric efficiency calculated with measured dietary energy concentrations in 75 to 118 kg finishing pigs [1]

	Sex			Stocking density Pigs per pen			Diet regimes Dietary NE (Mcal/Kg)				*P*-value[2,3,4]				
												Treatment		Linear Contrast	
	Barrow	Gilts	SEM	14	17	20	Low	Medium	High	SEM	Sex	Density	NE	Density	NE
n, pens	27	27		18	18	18	18	18	18						
Measured caloric intake, Mcal/d[5]	8.31	7.47	0.14	8.02	7.95	7.70	7.37	7.96	8.34	0.15	<0.01	0.001	<0.01	<0.01	<0.01
Phase 1 [5]	7.41	6.72	0.21	7.29	7.06	6.85	6.50	7.06	7.64	0.22	<0.01	0.01	<0.01	0.002	<0.01
Phase 2	8.86	7.76	0.17	8.57	8.34	8.04	7.98	8.44	8.52	0.19	<0.01	0.04	0.02	0.01	0.01
Phase 3 [5]	8.85	8.10	0.22	8.30	8.83	8.29	7.67	8.44	9.31	0.26	0.01	0.21	<0.01	0.98	<0.01
Measured caloric efficiency, Mcal:Gain	0.16	0.15	0.01	0.15	0.15	0.15	0.16	0.15	0.15	0.01	<0.01	0.90	<0.01	0.82	<0.01
Phase 1 [5,7]	0.18	0.18	0.01	0.17	0.18	0.19	0.19	0.19	0.16	0.01	<0.01	0.05	<0.01	0.02	<0.01
Phase 2	0.14	0.16	0.01	0.15	0.15	0.15	0.15	0.15	0.15	0.01	<0.01	0.56	0.93	0.47	0.70
Phase 3 [6,7]	0.12	0.13	0.01	0.13	0.12	0.13	0.14	0.12	0.12	0.01	0.23	0.66	0.001	0.99	<0.01

[abc] Within a row and treatment, means without a common superscript differ ($P < 0.05$).
[1] Data presented on an as fed basis, Phases were fed from; Phase 1 (75 to 90 kg), Phase 2 (90 to 105 kg), Phase 3 (105 to market).
[2] *P*-values and linear contrast: density = stocking density, NE = dietary net energy.
[3] Dietary energy × stocking density ($P > 0.05$).
[4] Quadratic contrasts were not significant.
[5] Sex × dietary energy ($P < 0.05$).
[6] Sex × dietary energy ($P < 0.10$).
[7] Sex × stocking density ($P < 0.10$).

B. Appendix B

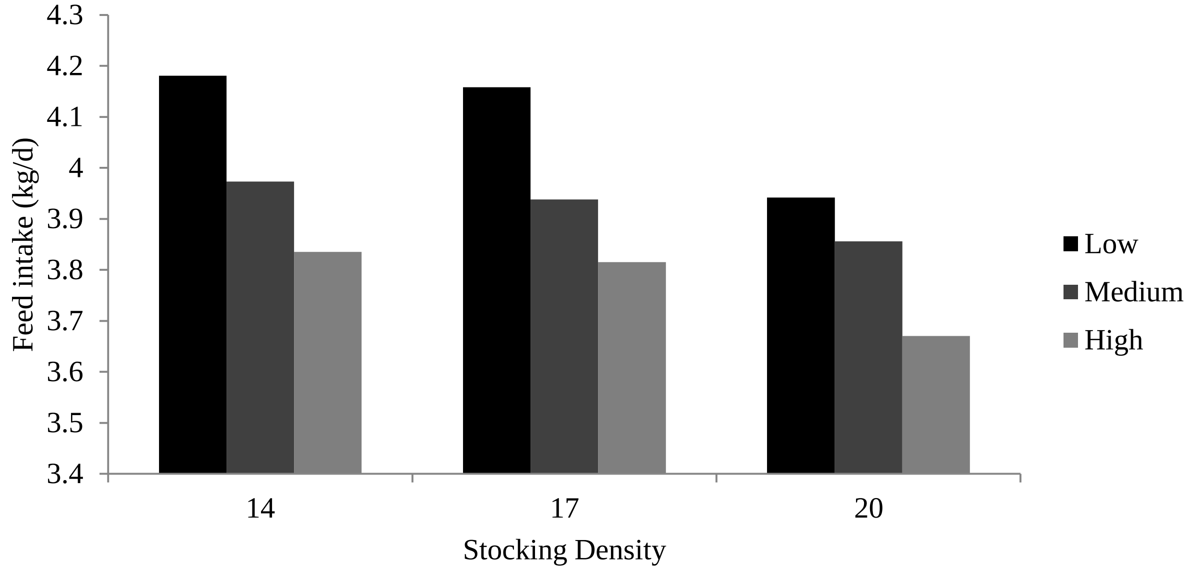

Figure B.1. Lack of an interaction between dietary energy and stocking density on ADFI in 75 to 118 kg finishing pigs (stocking density × dietary energy, $P > 0.10$; SEM = 0.09).

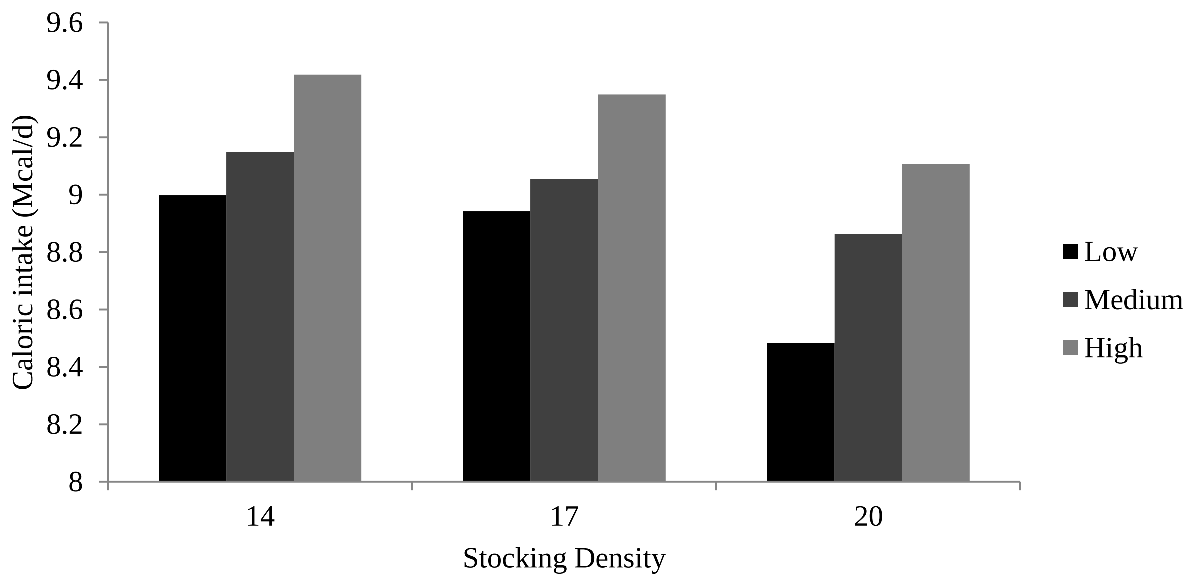

Figure B.2. Lack of an interaction between dietary energy and stocking density on caloric intake in 75 to 118 kg finishing pigs (stocking density × dietary energy, $P > 0.10$; SEM = 0.20).

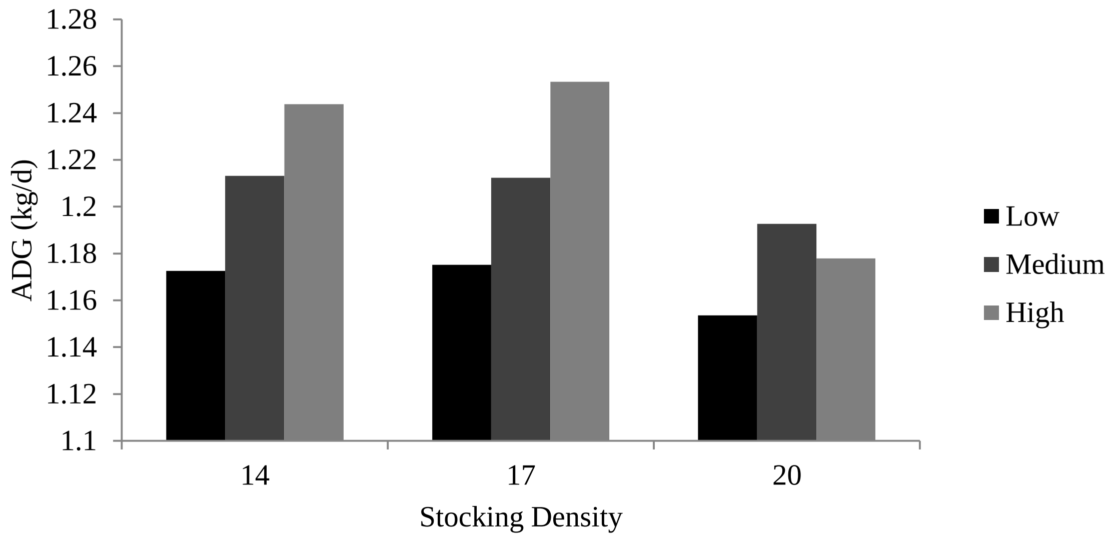

Figure B.3. Lack of an interaction between dietary energy and stocking density on ADG in 75 to 118 kg finishing pigs (stocking density × dietary energy, *P* > 0.10; SEM = 0.03).

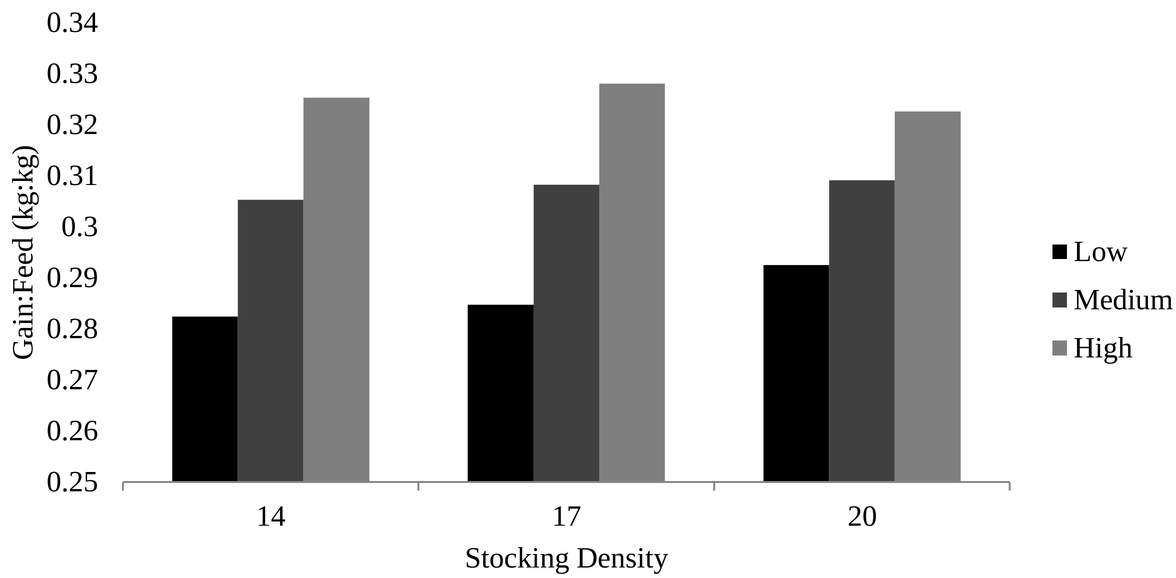

Figure B.4. Lack of an interaction between dietary energy and stocking density on feed efficiency (G:F) in 75 to 118 kg finishing pigs (stocking density × dietary energy, *P* > 0.10; SEM = 0.005).

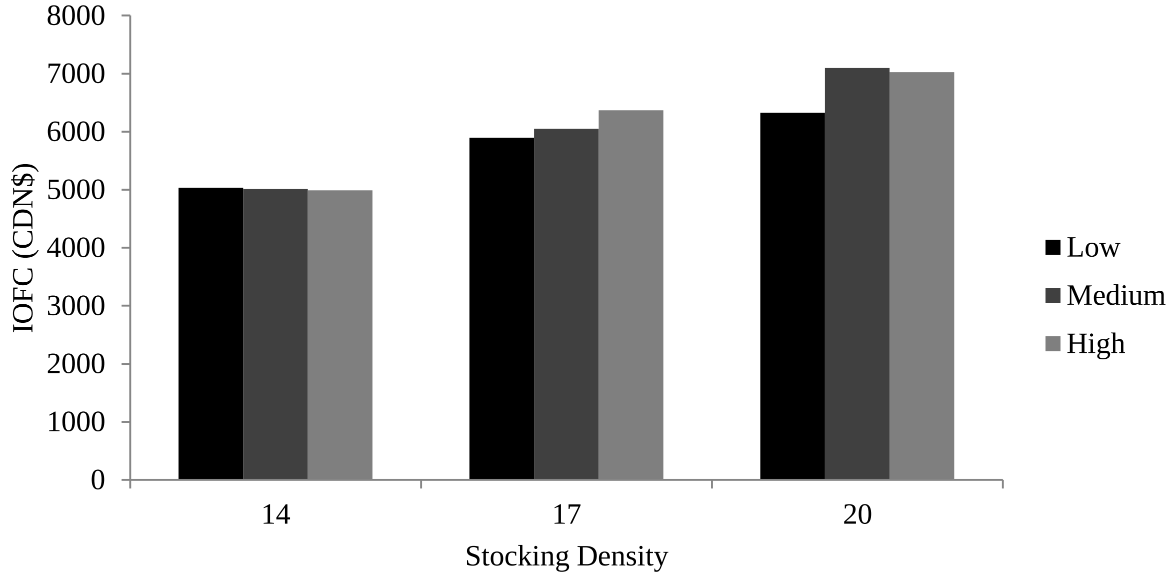

Figure B.5. Lack of an interaction of dietary energy and stocking density on income over feed cost (IOFC) in 75 to 118 kg finishing pigs (stocking density × dietary energy, *P* > 0.10; SEM = 158.94)

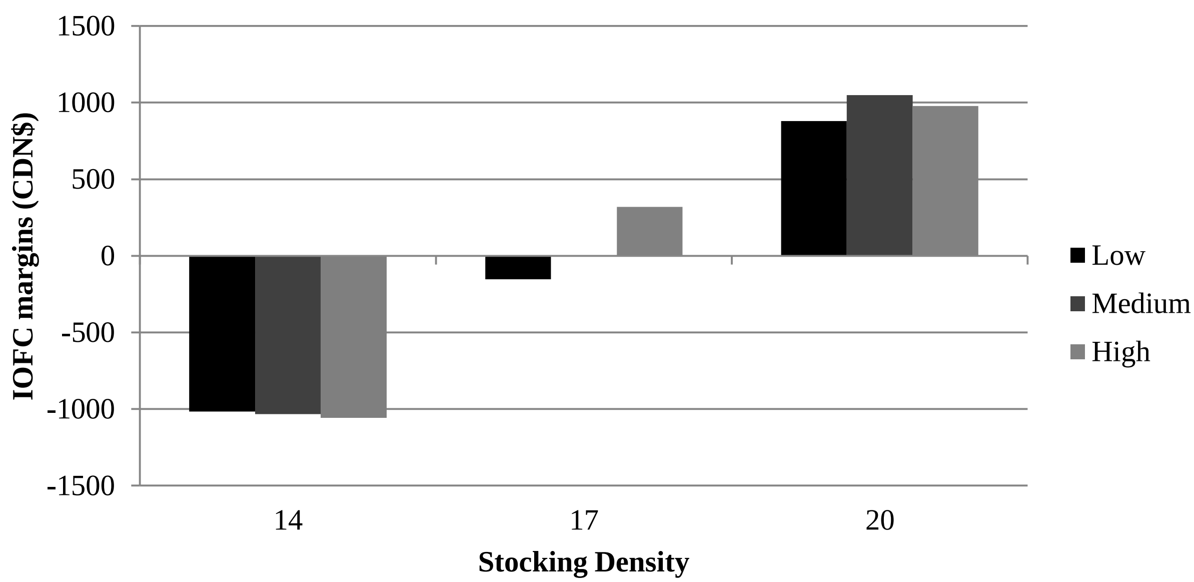

Figure B.6. Lack of an interaction of dietary energy and stocking density on income over feed cost (IOFC) margins in 75 to 118 kg finishing pigs (stocking density × dietary energy, *P* > 0.10) Margins are calculated from the pen of 17 fed the medium dietary energy