EFFECTS OF RESTRICTED FEEDING SCHEDULE DURING DEVELOPMENT AND GESTATION ON GILT AND SOW PERFORMANCE

by

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B.S. Iowa State University, 2001
M.S. Oklahoma State University, 2003

AN ABSTRACT OF A DISSERTATION

Submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Animal Sciences and Industry
College of Agriculture

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Abstract

The overall objective of these experiments was to develop management and feeding programs to increase sow longevity and productivity by improving welfare conditions. In Exp. 1, 208 gestating sows and 288 gestating gilts were utilized to determine the effect of feeding frequency (2 vs. 6) on performance and welfare issues. Feeding frequency had no affect on growth and reproductive performance in gestating sows; however, increasing the feeding frequency did improve the welfare measurements in this trial. Gilts fed six times a day did have increase ADG during d 0 to 42; however, there was no affect on performance from d 42 to farrowing. In Exp. 2 (630 pigs in 4 studies), increasing the feeding frequency (2 vs. 6) of a restricted feeding level increased growth performance of finishing pigs. This affect is likely due to the increase of available energy above maintenance when compared with the gestating sows. In Exp. 3, different feed drops used for delivering feed were evaluated. The Accu and the Ultra feed drops were more accurate than the Econo feed drop at angles of 90, 75, and 60°. The difference in accuracy is potentially related to the way that the drops attach to the feed line. However, the amount of feed that is collected in each drop appears to increase linearly as the feeder settings are increased. Thus, regression equations for the angle of the feed drop can be developed to adjust for the variability in the amount of accumulated feed. In Exp. 4, Alimet® was used to determine the TID TSAA:Lys ratio for ADG and G:F of 63 and 66% for Genetiporc and 61 and 56% for PIC pigs weighing between 10 to 20 kg. In Exp. 5, the optimal TID Lys:Calorie ratio was estimated to be 3.7 and 4.1 g Lys/Mcal ME for the Genetiporc and PIC pigs weighing between 10 to 20 kg . The ratios were than validated at two energy levels and the

amount of TID Lys that was used for lean gain was similar for both genetic lines at approximately 20 g of Lys for each kg of gain.

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Dedication

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CHAPTER 1 - Influence of energy and amino acid intake during gilt development and on sow productivity

INTRODUCTION

The nutritional management of gilts and sows has evolved over the past several decades as a result of increased genetic improvements in growth and reproduction performance. The removal rates in today's commercial herds are commonly in excess of 50% (Deen and Sukumaran, 2003), which usually transmit to a mean parity between three and four at removal (Lucia et al. 2000). With these high culling rates, gilts can constitute a large portion of commercial breeding herd inventories. Thus, replacement gilts are a critical component of the breeding herd and it is essential to understand the interactions between nutrition and management practices (Almeida et al. 2000). Furthermore, feeding practices at each production stage have specific objectives and must be geared to a long-term beneficial reproductive outcome (Trottier and Johnston, 2001). The feeding of gestating sows is not only concerned with optimizing fetal survival and growth, but with maximizing voluntary feed intake during lactation as well.

Welfare status of animals for meat production has received more attention in recent years. This is in part because it is not ethically acceptable from an animal welfare perspective to base pork production from sows that are not capable of handling the physiological stress (Serenius and Stalder, 2006). Currently, 60 to 70% of sows in the US are housed in stalls throughout gestation (Barnett et al. 2001); however, public perception of welfare may motivate producers to gestate sows in a group housing system. Recently, ballot initiatives banning gestation crates have passed in Arizona and Florida and Smithfield Foods Inc. (Smith, 2007) and Maple Leaf Foods (Arnot and Gauldin, 2007) have decided to phase out the use of stalls over the next decade. The argument for housing sows in a group housing environment instead of gestating stalls is because of the increased space and social contact (Scientific Veterinary Committee, 1997; Bracke et al. 1999; Bracke et al. 2002). However, when sows are gestated in a group housing system, aggression among pen mates is the main concern for producers (Kirkden and Pajor, 2006). The objectives of the present review are to characterize the effects of nutrition and management strategies on the development of gilts and productivity of sows.

BIRTH TO SELECTION

Pre-weaning and nursery growth.

Several studies (Nelson and Robison, 1976; Jensen et al., 1983) have shown positive correlation between pre-weaning growth rate and the size of the first parity litter. Martin and Crenshaw (1989) reported an increase in subsequent ovulation rates in gilts that received ad libitum intake during the first 28-d postnatal compared to gilts that were restricted in feed intake. However, litter size was not influenced in their study. According to Young (2004a), selected replacement gilts should be reared in small litters of a maximum of 8 pigs to allow for high pre-weaning growth and weaning weight to have a positive association on the reproductive performance.

Nutrition during rearing.

There has been an enormous amount of research conducted on the effect of nutrition in rearing on gilt development and longevity. Trottier and Johnston (2001) have stated the nutrition of gilts during rearing may effect reproductive productivity. Restricting energy intake during rearing is implemented to limit mature body size with a goal of reducing locomotor problems that are commonly associated with larger females. Earlier studies have shown that restricted energy intake in rearing resulted in greater sow longevity (Snoeyen, 1979; van Erp, 1980; den Hartog and van Kempen, 1980). One concern of restricting feed, energy, and protein or amino acids may be the adverse affect on the onset of puberty. However, Aherne et al. (1999a), Rozeboom (1996a), and Klindt et al. (1999; 2001) report that a restricted feeding will not delay the onset of puberty and may increase the number of live embryos at d 30 of gestation.

Conversely, ovulation rates at third estrus increased in sows fed diets formulated to maximize protein deposition during rearing (Cameron et al., 1999; Slevin et al., 2001). Recent research (den Hartog and Verstegen, 1990; Gill 1996) showed restricting lysine intake by approximately 50% of the calculated requirement of gilts between 30 kg and breeding reduced live weight gain while body lipid content increased and resulted in delayed puberty. These finding are further supported by Gill (2000) who showed that gilts had greater total born in their first litter when fed a diet containing 1.0% total lysine compared to 0.5% total lysine during rearing. Greater weight gains were found in rearing when feeding diets with higher ideal protein:energy ratios (Gill, 1996), but fast growing pigs appear to be more prone to locomotor problems (Gill and Taylor, 1999). The amount of dietary amino acids fed to gilts during rearing is important to allow for optimal growth potential. Subsequently, some producers may over supply protein or synthetic amino acid to achieve this growth potential. Not only is this costly and wasteful, but as Long (1998) pointed out, gilts provided ad libitum access to a high-energy, high-protein diet had the poorest longevity through four parities.

Growth rate in rearing.

Earlier studies have implied that excessive weight gain in rearing may lead to locomotor problems and, thus, reduce lifetime productivity due to premature culling (Jongbloed et al., 1984; Sorensen et al., 1993; Gill and Taylor, 1999). This is contradicted by evidence that supports the conclusion that growth rate has no detrimental effects on lifetime reproductive performance (Aherne and Williams, 1992; Rozeboom et al., 1996b; Aherne et al., 1999b; Young, 2004a). In addition, lean growth rates of gilts from 50 kg until the initiation of puberty has shown no effect on age of puberty (Cameron et al., 1999; Patterson et al., 2002). On the other hand, Beltranena et al. (1991a) proposed that gilts with high growth rates (> 0.7 kg/d, birth to puberty) achieve puberty earlier then gilts with slower (< 0.5 kg/d) growth rates. Young (2004a) reports that under commercial conditions gilts with growth rates ranging from 0.46 to 1.0 kg/d from 38 to 125 kg had no effect on total pigs produced or the percentage of gilts culled to the end of parity 3. Tummaruk et al. (2001) conducted a large retrospective study in Sweden comparing gilts with a greater growth rate with gilts with a lower growth rate from birth to 100 kg live weight and showed that faster growing gilts had larger litter size (parities 1 to 5), shorter weaning-to-service interval (parities 1 to 5), and a higher farrowing rate from (parities 2 to 5). Faster growth rates may increase body reserves at first service and farrowing, thus attributing to the positive reproductive performance.

Lean growth rate in rearing may optimize litter productivity and lifetime reproductive output (Gill, 2000). However, the possible consequences of maximizing lean growth rates in gilts include an increase in mature body weight, increased maintenance costs, and housing limitations (Patterson et al., 2002). Conversely, growth restriction generally delays puberty attainment in gilts (Le Cozler et al., 1999). Therefore, it appears that a feeding and management regimen that allows acceptable levels of growth during the rearing period will optimize subsequent reproductive performance.

SELECTION TO FIRST ESTRUS

First estrus – Body composition, weight and age.

Numerous research trials have scrutinized the role of body composition and live weight on age at first estrus. Previous researchers hypothesized that first estrus takes place only after reaching a minimum level of lean mass (Cunningham et al., 1974) or fat depth (den Hartog and van Kempen, 1980; Frish, 1980; Beltranena et al., 1991a), or a specific ratio of fat to lean (Kirkwood and Aherne, 1985). Furthermore, first estrus has been linked with a critical growth rate (Rozeboom, 1999; Beltranena, 1992; Rydhmer et al., 1994) and age (Hughes, 1982). However, in other studies, gilt age at first estrus was not well correlated to a specific minimum live weight, average daily gain, backfat thickness, or fat to live weight ratio (Young et al., 1990a). Rozeboom et al. (1996b) and Friend (1977) were in agreement with Young et al. (1990a) in which they found no relationship between daily gain from birth to puberty on the final age of puberty.

Puberty in gilts usually occurs between 200 and 220 days of age with a wide range between 102 to 350 days (Hughes, 1982). Patterson et al. (2002) found that puberty in modern gilts occurred between 131 to 201 d of age, with backfat levels of 9 to 35 mm, protein mass of 12.3 to 21.7 kg, and growth rates of 0.66 to 1.13 kg/d. Trottier and Johnston (2001) stipulate that a wide range in gilt age at puberty is not surprising due to the many factors that influence its occurrence. One such factor that will stimulate puberty in pre-pubertal gilts is exposure to a mature boar (Patterson et al. 2002) The factors of body composition and body weight at first estrus are interrelated with the production and management systems of each individual producers and are beyond the scope of this review.

FIRST ESTRUS TO BREEDING

Flushing.

Flushing is a management practice for gilts that increase the number of ova ovulated by offering elevated levels of feed 10 to 14 days before mating (Aherne and Kirkwood, 1985). The increased ovulation response is more due to increases in energy intake rather than protein intake. Anderson and Melampy (1972) suggested that about 6 Mcal of additional ME is needed to obtain optimal ovulation rates in restricted fed gilts. Trottier and Johnson (2001) suggested that an adequate flushing regimen consist of providing approximately 1.8 kg of a typical corn-soybean meal diet containing 3,200 kcal ME/kg. On average, ovulation rate increases two to three eggs, with larger increases reported, in response to flushing (Flowers et al., 1989). Quesnel et al. (2000) reported that restricting feed intake to one-third of ad libitum feeding from d 14 to 19 of the estrus cycle in gilts reduced the number of preovulatory follicles (16.9 vs. 20.6) before ovulation. The response to flushing in gilts is a result of reduced atresia of follicles and reflects the improved metabolic status (Beltranena et al., 1991b; Foxcroft et al., 1997). Flushing may not increase ovulation rate over that normally expected, but corrects a depression of ovulation rate imposed by dietary restriction that most gilts experience between puberty and mating. The intent of flushing is to have short-term impacts on ovulation rate without substantially influencing growth performance or body composition. It is obvious from this review to optimize the upper limit of litter size; gilts should be fed a flushing regimen for a minimum of 14-d before breeding.

Effect of weight, body composition and age of estrus at breeding.

The factors that affect sow longevity are weight, body condition and breeding age at the time gilts enter their productive life. However, there is considerable disagreement among researchers as to the factors mentioned above and their affect on lifetime performance. Tummaruk et al. (2001), in a large scale retrospective study, found that a 10 day increase in age at first mating increased litter size (0.1) in primiparous sows; although litter size for parity 4 and 5 sows was decreased (-0.05 to -0.10). Numerous studies (Nesovski and Veljanovski, 1986; Huang and Lee, 1995; Le Cozler et al., 1998; Aherne, 2001) further support the idea that mating gilts earlier in life decreases first litter size. However, Koketsu et al (1999) reported that conception in gilts at an early age (200 to 220 days) did not affect subsequent reproductive performance; in fact as age of conception increased, parity at removal and lifetime piglet production decreased.

There have been numerous studies investigating the relationship between age at first service in gilts and the size of the first litter produced. A number of these trials contradict each other as it has been suggested that early mating of gilts will reduce (Nesovski and Veljanovski, 1986; Daza et al., 1992; Le Cozler et al., 1998), increase (Noguera and Gueblez, 1984; Koketsu et al., 1999; Aherne, 2001), or have no effect (Culberston and Mabry, 1995; Huang and Lee, 1995; Clark, 1986; Rozeboom et al., 1996b) on lifetime performance. In addition, other studies have suggested that gilts that are very old at first mating (> 260 d) have reduced lifetime performance (Le Cozler et al., 1998; Aherne, 2001; Young et al., 2004b).

There is a plethora of debate on the influence of gilt body composition at their first service on long-term sow longevity and productivity. However, research involving these factors is limited because investigating trials take an extreme amount of time and are expensive. Gaughan et al. (1995) found that backfat depth at mating was positively correlated to lifetime productivity in sows. In that study, sows were grouped into lean, medium, and fat categories and sows that were lean at selection produced fewer pigs over their lifetime. However, some studies (Young et al., 1990b; Newton and Mahan, 1993; Rozeboom et al., 1996b) suggest that there was no relationship between weight or backfat depth at first service and sow longevity. A multitude of published results support the idea that gilts with large body reserves are prone to have a more productive life than their lighter, leaner counterparts in the breeding herd (Kirkwood and Thacker, 1992; Gaughan et al., 1995; Challinor et al., 1996; O'Dowd et al., 1997).

It is frequently recommended to breed gilts at their second rather than first estrus to increase first litter pig size (Young et al., 1990b; Rozeboom et al., 1996b). However, den Hartog (1984) and Le Cozler et al. (1999) found that only gilts fed a high (ad libitum) level of energy intake during rearing experienced an increase in first litter size. Smits (unpublished data, cited by Hughes, 2002) suggests that heavier gilts (greater than 140 kg vs. less than 100 kg) had greater first litter size (10.7 vs. 9.0 piglets). There has been little evidence to suggest a relationship between breeding beyond the second estrus and increased sow longevity. This review suggest a target breeding weight of approximately 140 kg and delaying breeding gilts beyond their second or third estrus (> 260 d of age) has unfavorable economic consequences.

BREEDING TO FARROWING

Energy and protein requirements.

The NRC (1998) reports the daily energy requirements of the gestating sow as the sum of the requirements for maintenance (ME_M = 106 kcal ME/kg $BW^{0.75}$), maternal weight gain ((87 + (0.12171 × BW gain, g)), and products of conception (35.8 kcal/ME × number of fetus). According to Noblet et al. (1990), maintenance represents 75 to 85% of the total energy requirements during pregnancy. Similar to the requirements for energy, essential amino acid (AA) requirements during pregnancy is the sum of requirements for maintenance, fetal and uterine growth, and maternal tissues accretion (Dourmad et al., 1999). The true ileal digestible lysine requirement for maintenance is 36 mg/kg $BW^{0.75}$ (NRC, 1998). The AA requirement for maternal gain and products of conception constitutes the largest proportion of the lysine requirement (NRC, 1998). Pettigrew (1993) suggests that total lysine requirement for gestating gilts ranged from 11 to 14 g/d.

The most desirable amount and composition of maternal gain during pregnancy is a subject of much interest to pork producers and nutritionists. Numerous gestation trials have studied the effect of protein and fat reserves on subsequent lactation performance. Clowes et al. (2003a, b) stated that loss of 9 to 12% of existing body protein mass during lactation is detrimental to piglet growth and ovarian function. Clowes et al. (2003b) suggested that a large body protein mass at farrowing may act as a protective factor in primiparous sows to ensure higher litter growth rates and ovarian follicle development. However, excessive feed intake in primiparous sows may result in backfat levels greater than 21 mm at farrowing. The high backfat is typically associated with reduced feed intake during lactation which results in body weight and fat loss (Dourmad, 1991; Weldon et al., 1994; Revell et al., 1998a; Young et al., 2004a).

Early gestation.

Pork producers are concerned with feed intake during the early post-mating period and the impact embryo survival. It has long been known that a severe under-nutrition (< 1 kg/d) in early gestation may reduce embryo survival (Pond et al., 1968; Speer, 1990). On the other hand, high feed intake similar to flushing during early gestation decreases embryo survival (den Hartog and van Kempen, 1980; Jindahl et al., 1996). Although, decreased embryo survival has not been found in some studies (Rozeboom et al., 1993; Cassar et al., 1994). After flushing, embryo survival is maintained if feed intake is reduced to near maintenance levels immediately after mating (Jindahl et al., 1996). The impact of high levels of feed intake on embryo survival during the first few days of pregnancy is likely caused by increases in hepatic blood flow and clearance of progesterone resulting in decreased concentrations of circulating progesterone (Jindahl et al., 1996, 1997). Circulating levels of progesterone may aid in orchestrating the synchronous development of the embryos and prepare the uterus for pregnancy (Jinhahl et al., 1997). However, other studies have not seen the changes in progesterone levels and effects on embryo survival in gilts as a result of nutritional manipulation (Dyck and Strain, 1983; Pharazyn, 1991; Cassar et al., 1994; Ashworth et al., 1999). Novak et al. (2003) suggests that a change in feed intake alters oocyte quality and steroid dependent priming of the oviductal environment. Gilts with high and low embroyonic survival have vastly different follicular development and oocyte quality which may be related to differences in hormone profiles (Blair et al., 1994; Jindal et al., 1996; Almeida et al., 2001). In general, to maximize embryo survival in gilts the feeding level should be reduced to a maintenance level for approximately 72 hours after mating.

Late gestation.

The majority of mammary development that occurs in gestation is after d 75 postmating (Trottier and Johnston, 2001). Thereafter, there is an exponential growth in the concentration of DNA and RNA in the mammary gland (Kensinger et al., 1982). Weldon et al. (1991) studied the effects of energy intake on mammogenesis and found that increasing energy intake in gilts from 5.75 to 10.5 Mcal ME daily after d 75 of gestation reduced mammary weight, DNA, and RNA of parenchymal tissue, thus potentially reducing milk synthesis. Head et al. (1991) and Head and Williams, (1999) found similar results when gilts fed a high energy level resulted in half the mammary alveolar cells and a quarter of the mammary DNA concentration of gilts fed normal energy levels. Gilts that were fed high energy with low CP were fatter at the end of gestation and nursed slower growing litters. However, backfat depth for gilts fed both the control and high energy diets (P2 backfat of 26 vs. 35 mm) were much greater than current commercial targets for modern genetic lines. However, others have not found the same reduction in mammary gland development and litter growth rate (Smits et al., 1995; Revell et al., 1998b) by feeding high energy in gestation. Furthermore, Howard et al. (1994) suggested that parenchymal DNA and RNA levels, and thus mammogenesis, was not affected by feeding high levels of energy intake in gestation.

Contrary of the effects of energy intake, there have been no adverse effects of high lysine and CP intakes observed on mammogenesis in the pig. The DNA of mammary tissue on d 105 of gestation were similar in gilts fed differing total lysine (4 to 17 g/d) and CP concentrations (104 to 330 g/d; Weldon et al., 1991; Smits et al., 1995). However, Shields et al., (1985) saw a reduction in litter growth rates in lactation when gilts were fed very low (91 vs. 255 g/d) CP levels in gestation.

Young et al. (2004b) observed energy requirements in late gestation related to the exponential fetal growth to be 4.0 kJ/kg $BW^{0.75}$ per d from d 90 to 110 of gestation. Crude protein requirements also increase because N retention is estimated to increase from 9 to 10 g/d at mid-gestation to 17 to 18 g/d in late gestation (Noblet et al., 1985; Dourmad et al., 1996). Therefore feeding level should be increased in the last two weeks of gestation to meet the added nutrient requirements for fetal growth.

EFFECT OF FEEDING FREQUENCY ON THE RATE OF BODY WEIGHT GAIN

The effect of feeding frequency on metabolism and rate of body weight gain has been the subject of investigation for many years. Comparing the potential benefits of eating several small meals or gorging on a large single meal has been the focus of much animal and human research with no clear consensus (Bray, 1972; Jenkins et al., 1989; Wolever, 1991; Jenkins et al., 1995;

Bellisle et al., 1997; Powell et al., 1999; Taylor and Garrow, 2001). This review will investigate the influence of feeding frequency on digestibility and metabolizablity of dietary energy.

Increasing the feeding frequency of group housed pigs is positively correlated with digestibility coefficients (de Haer and de Vries, 1993a), which may be due to a more constant digesta flow in the small intestine (Ruckebush and Bueno, 1976; Sissons and Jones, 1991; van Leeuwen et al., 1997), and by increasing digestive enzyme production. Botermans et al. (2000) fed a constant total amount of feed over an increasing number of meals (1 to 12) which altered the pattern of exocrine pancreatic secretion and increased protein output, chymotrypsin, and lipase activity. When Botermans et al. (2000) fed pigs 12 times the lipase activity tended to increase by 46% compared with once daily. This is similar to the response seen by Hee et al. (1988) of an increased lipase activity of 38% when pigs were fed three times per day compared to once per day. The increase of exocrine pancreatic secretion during feeding was previously shown (Botermans and Pierzynowski, 1999) to be independent of the amount of feed consumed. Botermans et al. (2000) demonstrated that feeding similar amounts of feed in small doses several (12) times per day stimulated the volume of secretion, protein output, and activities of lipase, amylase, and chymotrypsin. This information is in agreement with de Haer and de Vries (1993b) which stated that stimulation of exocrine pancreatic secretion by feeding frequently might improve the digestibility and utilization of nutrients for metabolism.

Meal feeding, the consumption of food a single short daily period (Leveille 1970), as opposed to nibbling, caused an improved efficiency of energy utilization rates (Cohn 1963; Kekwich and Pawan 1966) whereas no differences in caloric efficiency were evident in pigs fed once or five times daily (Friend and Cunningham 1964). Sharma et al. (1973) found the coefficients for DE and ME were 88.4 and 85.1%, respectively, of the GE and were not different for pigs fed two or five times daily. The change in feeding frequency did have a numerical effect on the estimate of energy requirement for maintenance. Pigs fed five times daily had a higher DE and ME maintenance requirement then pigs fed twice a day (DE = 136.3 vs. 115.9 kcal/$BW^{0.75}$, kg; ME = 131.13 vs. 111.42 kcal/$BW^{0.75}$, kg). This is also representative in activity level expressed as fasting heat production (FHP) of multiple fed pigs vs. pigs fed twice daily. Pigs fed five times a day expressed a FHP/$W^{0.75}{}_{kg}$ of 98.17 kcal/d vs. 85.31 kcal/d for pigs fed twice a day. The apparent efficiency of utilization of ME for maintenance for pigs fed five times a day was similar to pigs fed twice a day (74.86 and 76.57%, respectively). However, the efficiency of available ME utilization for growth was higher for pigs fed five times a day vs. pigs fed twice daily (61.5 vs. 55.1%). In this study, the pigs fed five times a day had higher maintenance requirements, but were also more efficient converters of the available ME above maintenance for tissue deposition. Sharma et al. (1973) further stipulated that the total requirement of ME for maintenance and production for pigs fed twice or five times daily would be similar. When expressed on a NE basis the energy available for maintenance (NE_m) was similar for pigs fed twice or five times daily (2.90 vs. 2.82 kcal/g DM). However, the net energy value for gain (NE_g) for pigs fed five times daily was higher than for pigs fed twice daily (2.32 vs. 2.08 kcal/g DM). Finally, Sharma et al. (1973) concluded the use of the NE system, although more complex, revealed an influence of frequency of feeding on energy utilization that was not evident by the use of the simpler DE and ME systems.

Work by other researchers (van Leeuwen et al., 1997; Friend and Cunningham, 1964) did not demonstrate differences in digestibility or performance between pigs fed the same total amount of feed in large meals or several small meals. However, de Haer et al. (1993b) found that pigs that were fed the same feed intake levels in frequent small meal had a lower daily gain, but leaner carcasses than pigs receiving a single large meal which may be due to higher losses of nutrients for behavioral activity. According to van Putten (cited in Hessel et al., 2006), pigs engage in more rooting activity when fed a restricted diet in a very short amout of time.

The effect of meal frequency on glucose and lipid metabolism and their relationship to the health of human subjects has also been a matter of discussion (Lundin et al., 2004). Studies by Ellis in 1934 (cited by Lundin et al., 2004) suggested that insulin requirements in patients with diabetes could be reduced by increasing meal frequency. Gwinup et al. (1963; cited by Lundin et al., 2004) showed that normal and diabetic patients improved their glucose tolerance when shifting from three meals to a daily isocaloric diet of 10 meals. Furthermore, the closeness of one meal to the next determines the glycemic response the second meal with a smoother glycaemic response the closer the meals are together (Gwinup et al., 1963; cited in Lundin et al., 2004). This response is called the second-meal phenomenon (Jenkins et al., 1980) which may improve carbohydrate tolerance and reduce the insulin response the second meal by spreading the nutrient load from the first meal. Cohn (1964) found that increased meal frequency reduced total cholesterol, LDL cholesterol (Jenkins et al., 1989), and serum free fatty acids (Wolever, 1990).

The digestion and metabolism of nutrients is very complex. Nevertheless, increasing the feeding frequency has been shown to increase exocrine pancreatic secretions and may increase digestibility of nutrients. However, the affects on daily gain and feed efficiency are unclear at this time.

SOW WELFARE

Overview of the five freedoms.

Animal welfare is a persistent issue in many modern day societies and production agriculture. This may be particularly caused by the negative misconceptions of animal husbandry practices in the swine industry. Presently, one of the most controversial issues of conventional pig production is the individual housing of gestating sows. This is evident by the recent citizen initiated ballot measures in Arizona and Florida banning gestation crates as well as the decision by Smithfield Foods Inc. (Smith, 2007) and Maple Leaf Foods (Arnot and Gauldin, 2007) to replace sow stalls with group housing.

To counteract the growing criticism of production agriculture the British Farm Animal Welfare Council developed the Five Freedoms to give a conceptual guide for designing animal environments (reviewed in Webster, 1994). These criteria include the following: 1) freedom from hunger and malnutrition, 2) freedom from thermal or physical distress, 3) freedom from fear, 4) freedom from disease and injury, and 5) freedom to express most normal behaviors. This is a relatively straightforward procedure to strive for improved animal welfare. However, the last freedom is the only one that seems to bring up controversy (Ewing et al., 1999). This may be because the fifth freedom: 1) does not demand that specific undesirable physiological, health, or psychological states are prevented, and 2) the different versions of normal or natural behavior associated with individuals thoughts (Spinka, 2006). Thus, the boundaries of this freedom are not fixed and open to interpretation as it requires a general freedom for all kinds of behavior of the animal.

The complexities of natural behavior are high because animal behavior can be uniform across time and across individuals or between internal motivational states and the time dynamic of the stimuli from the environment (Jensen and Toates, 1993; Spinka, 2006). For example, nest building in sows starts about 15 h before the start of parturition (Damm et al., 2003). However, the duration and intensity of the nest building varies widely according to internal factors such as sow experience (Thodberg et al., 2002) and external stimuli such as building material (Damm et al., 2003), space (Damm et al., 2002), and temperature (Burne et al., 2001). If the sow believes the nest to be adequate with the surrounding environmental conditions they may stop nest building (Arey, 1997). A second example is behavioral reactions to situations caused by genetic improvements of the modern swine. Spinka (2006) suggests that the appetites of the modern sows have been increased through selection for high feed intake. During gestation their feed intake is reduced to 60% of ad libitum intake (Lawrence et al., 1988). Although this ration is adequate for maintenance and growth, Spinka (2006) suggested that the sow may find it a threat of starvation. Consequently, Lawrence and Terlouw (1993) suggest that sows may engage in intensive foraging attempts, such as bar biting and sham chewing.

The performance of natural behavior does not necessarily make a positive contribution to the welfare of farm animals. Behavior such as establishing dominance in a group setting is natural, but decreases the welfare of individual sows and their pen mates. Therefore, gauging welfare issues in swine is extremely difficult as behavior patterns may change in different environmental situations and certain behavior does not necessary mean that animals are behaving “unnaturally”. However, Kanis et al. (2005) stated that swine breeding organizations may derive an economic model similar to the dairy industry (Wickman in 1979; cited by Goddard, 1998) that is possible to attain breeding trait goals with non-economic but societal importance goals.

Welfare of gilts and sows in stalls or group housing environment.

Evaluating how housing affects the welfare of gestating swine is difficult because every system has strengths and weaknesses with respective consideration of the nutrition program, production system, and management practices. The most pressing concerns when evaluating housing include the following: 1) animals should be healthy and thriving; 2) emphasis on prevention of serious pain, hunger, fear, and other forms of suffering; and 3) animals should be able to live in a manner consistent with the nature of their species (Task Force Report, 2005). While it is generally acknowledged that the importance of these elements may vary, no assessment of animal welfare is complete unless all elements are considered.

In the U.S., gestation stalls are the dominant housing system for gestating sows. The commercial industry has favored stalls over group housing because of the increase in productivity, lower capital investment than group housing and automatic feeding systems, and a reduction in aggression that is associated with stalls (Task Force Report, 2005). Recently, concerns about production practices of farm animals have gradually increased. This has amplified the pressure on the U.S. swine industry and animal scientists to consider alternatives to gestation stalls. However, when evaluating new housing systems, the criteria of productivity, labor requirement and management, welfare and health, and investment costs must be investigated; only then is an appropriate evaluation of farm systems possible (den Hartog et al., 1993). This review will attempt to explain the differences between gestating stalls and group housing on these criteria.

Productivity of sows in group housing and gestating stalls.

There is little growth performance data available that provides a complete analysis on ideal housing of gestating sow because of the requirements for a large number of experimental animals and facilities, both of which are expensive. Furthermore, how individual sows respond depends on environmental conditions within the pens. Likewise, an individual gestation stall is a single unit and might not be an appropriate representation when compared to sows housed in a dynamic or static pen. However, an argument can be made is that a contemporary group of sows (i.e. a collection of sows housed in several stalls and a group pen) would be a uniform block of experimental units that would provide a replicated comparison of welfare effects (Task Force Report, 2005). Also other factors, such as difference in feeding system, floor type, bedding, management style, and local environment, may make statistical analysis even more challenging.

Backus et al. (1991) found that sows housed in groups had a lower weight at first and second farrowing when compared to sows housed individually in gestating stalls. Conversely, older sows of four and higher parity were heavier then their counterparts housed in stalls. This may be explained by the interaction between larger, older sows and younger sows that have a lower social order within the group. Geverink et al. (2004) placed sows in a climatic respiration chamber and found that group-housed gilts showed higher energy metabolism and lower energy requirements for maintenance than gilts housed in stalls. This was hypothesized to be caused by the higher BW and fat retention of the group housed gilts decreased ME_m or the higher ME_m in gilts housed in stalls. The increase in ME_m of stall housed gilts is believed to be caused by an increased stress level due to their housing environment (Schrama et al., 1997). Previously, Geverink et al. (2003) showed that housing gilts in stalls caused a change in circadian cortisol rhythm, reduced growth, and increased stomach wall damage.

England and Spurr (1969) used rate of estrus detection in sows and gilts housed in stalls or groups and found that estrus was not affected by housing environment. Furthermore, Schmidt et al. (1985) studied multiparous sows housed in individual gestation stalls or in pens of 4 to 5 sows for a period of 2.5 years and found that the weaning to estrus interval was not different. However, the review by McGlone et al. (2004b) found a reduced weaning to estrus interval for sows housed in stalls versus those housed in groups. This was similar to Backus et al. (1997)

which found a decrease of 0.7 to 1.1 days in the weaning to estrus interval for sows housed in stalls versus those housed in groups.

Peltoniemi et al. (1999) found in a retrospective epidemiological study of Finnish sow records between 1992 and 1996 that housing dry sows in groups increased the risk of not rebreeding. However, Schmidt et al. (1985) reported a higher farrowing rate in sows housed in groups compared to sows housed in stalls. Although, Love et al. (1995) revealed an interaction between season and feeding rate after mating on farrowing rate with improvement in farrowing rate of sows housed individually after mating during the summer and autumn period.

There are a limited amount of information on the affects of housing systems on conception rate among sows and gilts. Lynch et al. (1984) compared conception rates in group, tether, and stall housing and reported that group-housed sows had a much poorer performance attributable to a combination of failure to show estrus, lower conception ratio, and loss through injuries from fighting. However, the percent of sows conceiving in groups or stalls in other studies (England and Spurr, 1969; McGlone et al. 1989) did not differ significantly with respect to housing systems.

Behavior of sows in group housing and gestating stalls.

Behavior serves as a boundary between animals and their environments and is affected by various factors. Behavior can be an indicator of welfare problems such as the way poor posture may be an indicator of disease. Conversely, the lack of dominant or aggressive behavior may help to avoid the negative effects on welfare such as animal injury. Research into animal behavior plays an important role in the various welfare views described previously. According to the Task Force Report (2005), the general principles of behavior are: 1) those that emphasize the physical aspects of welfare believe that behavior plays a role in achieving good nutrition and optimal performance, 2) those that emphasize the mental aspects use behavior as an indicator of psychological state from preferences expressed through behavior, and 3) those who emphasize a natural approach use the ability to perform natural species behavior as an indicator of good welfare.

There have been relatively few behavioral studies that specifically addressed gestation stalls, although research on sows in tether systems may provide some information relevant to certain aspects of individual housing in general. A Task Force Report (2005) review stated that data from the scientific literature indicated that stalls and tethers have approximately similar effects on behavior when it comes to social interactions, available space and freedom of movement, feed restriction, aggression, and opportunities for the sow to control her environment; however, comparing stereotypical behavior is less straight forward.

Most housing systems currently used in the commercial swine industry for gestating sows are very different to the natural environment of wild or feral pigs. The modern gestating housing systems deviate from what is found in nature relative to group size and composition, space allocation, and environmental complexity (Gonyou, 2001). In any social group of pigs of any size, a dominance order is formed with various sows becoming dominant, intermediate, and subordinate. Sows of lower dominance status are usually on the losing end of aggressive encounters and exhibit signs of stress in groups (Mendl et al., 1992). Although individual stall housing is not traditional to what is observed in nature, there is little in the literature to suggest that being housed individually in stalls is a hindrance to sows (Task Force Report, 2005). Matthews and Ladewig (1994) reported that sows housed individually in bedded pens appeared to be content and comfortable. Furthermore, the Task Force Report (2005) review stated that sows in free-access stall systems may choose to sleep in individual stalls rather than in physical contact with other sows. However, in colder climates, the inability of sows housed in stalls to huddle together may reduce thermal comfort. Matthews and Ladewig (1994) report that pigs will work for social contact; however, the motivation for social contact is more flexible than motivation for food.

Housing sows individually in stalls restricts their freedom of movement. This has recently increased the public concern about how sows are housed in production agriculture. This concern is intensified particularly when sows of high parity are housed in gestating stalls where the space provided is actually smaller than the body size of the sow (McGlone et al., 2004a). The size of the stall may influence the behavior of the sow in which they move less and take longer to lie down in smaller stalls than in larger stalls (Anil et al., 2002). According to McGlone et al. (2004a), fewer than 40% of modern sows fit within the conventional gestation stall (58 × 213 cm) without protruding outside. Intruding hooves in the neighboring stall may further decrease the comfort level and welfare of larger sows. Further research (Fredeen et al., 1978; Sather and Fredeen, 1982; Marchant and Broom, 1996) have suggested that lameness, reduced muscle tone and mass, reduced agility, and reduced bone strength result from inactivity.

The effect of group housing on the amount of sow movement is not well understood and may be confounded by environmental factors such as deep bedding. It is known that feral pigs travel 14 to 27% of the time, or walk about 1 km/d. This probably represents travel necessary to obtain nutrients (Copado et al., 2004). In a recent study, Marchant-Forde and Marchant-Forde (2004) reported that the activity of gestating sows in straw bedded pens that were fed a restricted diet. These sows walked 1 to 3% of the time (approximately 15 min/d) throughout gestation with the amount of lying increasing from 54 to 73% of the time by week 15 of gestation. Hulbert and McGlone (2006) have also shown that sows would lie on the ground about 96% of the day when fed either by a drop feeding or trickle feeding method. This was regardless of being housed in groups or individually stalled. Therefore, the activity level of sows is dependent on environment and when high quality feed and water are readily available sows are relatively inactive. However, Boyle et al. (2002) found that sows previously housed in groups were more restless during farrowing, thus stress levels may increase when sows are moved to the farrowing crate.

The practice of feeding limited amounts of concentrated diets to gestating sows is also related to welfare concerns. Sows that are limit fed probably remain hungry for much of the day and exacerbate the effects of housing because of the increased competition for food among sows housed in groups (Terlouw et al., 1991; Lawrence and Terlouw 1993; Terlouw and Lawrence 1993; Arey and Edwards 1998). Appleby and Lawrence (1987) have also found that limiting feed appears to make sows more restless and increases their motivation to forage for food. Obviously, this behavior cannot be fulfilled in the modern confinement building regardless if sows are housed in stalls or groups. Whether sows are housed in stalls or pens without appropriate environmental complexity, hunger may lead to abnormal movement of their snouts or mouths toward objects within their present environment. Fraser and Broom (1997) state that sows may continually play with a nipple drinker and using 2 to 3 times the amount of water they would normally use. However, Olsen et al. (2002) concluded that providing pigs with a complex environment improved their welfare as indicated by reduced aggression.

Fraser and Broom (1997) define stereotypic behavior as “a repeated, relatively sequence of movements which has no obvious purpose”. The type of stereotypic behavior exhibited by sows kept in stalls and pens are repetitive bar biting, rooting, and rubbing on pen surfaces. Stereotypic behavior is more often observed when sows are housed in stalls than in pens

(Arellano et al., 1992; Vieuille-Thomas et al., 1995; Stolba et al., 1989). The percentage of the day that sows were found to spend occupied in stereotypic behavior varied considerably among studies, from less than 1% (Morris et al., 1993) to as high as 26% (Spoolder et al., 1995) and as high as 46% (Cronin and Wiepkema, 1984). Furthermore, Appleby and Lawrence (1987) found considerable variation among individual sows with the percentage of time spent occupied in stereotypic behavior ranging from 0 to 61%. Some research suggests that stereotypic behavior may have more to do with limit feeding and lack of opportunity for foraging than with restriction of movement (Appleby and Lawrence, 1987; Terlouw et al., 1991; Lawrence and Terlouw, 1993; Terlouw and Lawrence, 1993; Bergerson et al. 1996). Simply allowing sows to turn around did not reduce this behavior as Bergerson et al. (1996) compared conventional and turn-around gestation stalls and found no significant reduction of stereotypic behavior. In addition, Kirkden and Pajor (2006) found no evidence that stall-housed gestating sows recognize the increased social contact and space offered by a group pen to be important. Terlouw and Lawrence (1993) housed sows in tethers or group pens with two different feeding levels and observed a similar level of repetitive behavior when access to feed was restricted. Feeding sows housed in stalls more dietary bulk fiber may reduce stereotypic behavior (Robert et al., 1993); however, this was not always successful (McGlone and Fullwood, 2001). Fraser and Broom (1997) concluded that stereotypic behavior may help alleviated the effects of undesirable conditions; however this is not fully proven. Whether or not stereotypic behavior helps the animal cope in adverse condition, it is often considered a strong indicator of welfare problems (Stolba et al., 1984; Vestergaard, 1984; Mason, 1993; Wechsler, 1995).

The main concern of producers with a group housing system is aggression among pen mates. Physical injury as a result of aggression among group housed sows is of great economic and welfare concern for the swine industry. Aggression mainly occurs during mixing or forming pens (McGlone 1986; Luescher et al., 1990) and when sows are competing for food (Edwards 1992; Gjein and Larssen 1995). Aggression usually occurs during feeding and depends on the method of feeding (Edwards et al., 1993; Barnett 2001; Andersen et al., 1999); however, some aggression may also occur when competing for preferred lying areas (Edwards 1992). Aggression towards other sows can also lead to skin lesions and injury to the vulva. Vulva biting is most common in facilities that use electronic feeders that expose the hindquarters of sows in the feeders (Task Force Report, 2005). Furthermore, the design of group pens may increase the risk of vulva biting. The occurrence of vulva biting can be reduced by improvements in systems designs and management techniques such as barriers to allow sows to escape; however this event may not be eliminated (Rizvi et al., 1998; van Putten and de Burgwal, 1990). Feeding sows that occupy a group pen simultaneously may also remove the risk of vulva biting and other aggressive behaviors; however, housing sows in individual stalls is the only way to completely eliminate vulva biting.

CONCLUSION

The management of gilts and sows has become a critical issue in determining the overall productivity of the commercial industry. To ensure a long reproductive life in the breeding herd, a successful gilt development program should begin early in the gilts life. From the review of the literature it is clear that the gilts should enter the breeding herd with adequate tissue reservoirs to ensure a long breeding life. Also management factors such as welfare concerns involved with stalls and group housing are complex relationships between nutrition, genetics, and public perceptions. These are issues that should be addressed by responsible producers so that objective animal welfare measures, not the perception of welfare measure, are used in industry.

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CHAPTER 2 - Investigation into the effects of feeding schedule on body condition, aggressiveness, and reproductive failure in group housed sows[1]

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ABSTRACT: A total of 208 sows and 288 gilts (PIC Line C29) were used to determine the influence of feeding frequency (two versus six times per day) on performance and welfare measurements on a commercial sow farm in northeast Kansas. Treatments consisted of feeding similar amounts of feed to each sow or gilt over two (07:00 and 15:30) or six times per day (07:00, 07:30, 08:00, 15:30, 16:00, and 16:30 hours, respectively). There were 8 sows or 12 gilts in each pen. Gilts and sows were moved to pens after breeding. In gestating sows, there were no differences (P > 0.10) in ADG, backfat change, or variation in BW. There was a trend ($P < 0.08$) for sows fed twice a day to farrow more total number born, but number born alive or other reproductive performance were not different ($P > 0.10$) among treatments. Sows fed 6 times a day had increased vocalization during the morning ($P < 0.07$) and afternoon ($P < 0.01$) feeding periods compared with sows fed twice a day. Sows fed twice a day had more skin ($P < 0.01$) and vulva ($P < 0.04$) lesions as well as a small, but significant, increase in feet/leg ($P < 0.01$) and hoof ($P < 0.02$) problems. In this commercial facility, the standard management protocol required moving gilts to a different gestation facility. On d 42, two pens of gilts with similar breeding dates and treatment were combined and moved to another facility with larger pens until farrowing. Gilts fed six times a day had a tendency greater ADG ($P < 0.07$) from d 0 to 42, and a tendency greater ($P < 0.09$) backfat on d 42. After movement to the larger groups from d 42 to farrowing, ADG was similar ($P > 0.10$) for gilts fed twice or six times per day. Gilts fed twice a day had lower BW variation at d 42 ($P < 0.04$) and tended to at farrowing ($P < 0.10$). In gilts, there were no differences ($P > 0.10$) for reproductive performance, skin and vulva lesions, and leg/feet and hoof scores. In conclusion, there were few growth, farrowing, or aggression differences among gilts fed either two or six times per day. This suggests that either feeding method is suitable for group housed gilts. Among sows, feeding frequency resulted in few

growth or farrowing performance differences. Feeding six times per day did result in a small but significant reduction in skin and vulva lesions and structural problem scores while increasing vocalization. Increasing the feeding frequency from two to six times per day does not appear to have a dramatic negative or positive impact on performance or welfare of group housed gilts and sows.

Keywords: feeding frequency, feeding system, gestation, sow, welfare

INTRODUCTION

In many commercial swine facilities, sows are individually housed in gestation stalls; however, animal welfare concerns and equipment replacement costs may lead to increased usage of group housing. The welfare concerns are evident by ballot measures in Arizona and Florida banning gestation crates and decisions by Smithfield Foods Inc. (Smith, 2007) and Maple Leaf Foods (Arnot and Gauldin, 2007) to replace sow stalls with group housing. Because housing sows in groups allows for increased freedom of movement and social interaction, it is perceived to be more welfare-friendly than housing sows individually in stalls (Trottier and Johnston, 2001). Group housing is also thought to decrease chronic stress experienced by sows (Barnett et al., 1987) and speed the farrowing process (Ferket and Hacker, 1985). The social interactions, however, can also lead to greater aggressive behavior. Dominant sows, high on the social order, consume more feed than desired at the expense of less dominant sows and is likely to result in high fear and distress in the less dominant sows (Gonyou, 2001).

The ability to properly feed gestating sows in group housing has been one of the biggest detriments of group housing. Several approaches to feed group housed sows have been attempted, including feeding every other day, using feeding stalls within a pen, electronic sow feeders, trickle feeding, and ad libitum feeding of high fiber diets (Trottier and Johnston, 2001).

A recent approach used on some farms is multiple feedings (5 or 6 meals) spread over the feeding period each day. The theory behind multiple feedings is that offering feed more frequently may result in dominate sows eating their allowance, and then giving timid sows more opportunity to eat later in the feeding period, resulting in less variation. Our objective was to determine whether feeding group-housed gestating sows multiple times per day reduces variation in sow body weight, backfat thickness, aggressiveness, and feet and leg problems compared with twice per day feeding.

MATERIAL AND METHODS

The experimental protocols used in these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee.

A total of 496 group-housed gilts and sows were used to determine the influence of feeding frequency (two versus six times per day) on performance and welfare measurements. The experiment was conducted on a commercial sow farm in northeast Kansas that typically housed gestating sows and gilts in pens. Sows and gilts were managed differently in the experiment and thus procedures and data are presented separately.

A total of 208 sows were randomly allotted to treatments (13 pens/treatment) in a balanced incomplete block design. After weaning sows were moved to a breeding facility. Sows (average of 3 parities) received boar exposure and were housed in crates until detection of estrus, then inseminated twice. The following day, 24 to 40 sows were randomly allotted by parity and assigned to a pen (5 × 3 m; 8 sows/pen). Sows were weighed and backfat measured at the P2 position at the time of allotment and before introduction into the farrowing house. Standard farrowing records were recorded by farm personnel.

Two hundred eighty-eight gilts were allotted to treatments at breeding with 12 replicates per treatment in a balanced incomplete block design. Replacement gilts were selected for breeding and transported to a breeding facility. Upon arrival, gilts were housed in groups with boar exposure until estrus detection. Gilts were then inseminated twice and then were moved to pens (5 × 3 m) over approximately 4 d until there was 12 gilts each pen. Gilts were housed in this facility until d 42 of gestation. At this time, gilts of similar breeding dates and treatment were combined and moved to another facility with larger pens until farrowing. Thus, the 12 replicates per treatment where combined to give 6 replications per treatment after d 42 of gestation. Gilts were weighed and backfat measured at the P2 position at allotment, on d 42, and before farrowing. Each pen in the experiment contained half solid and half slatted flooring with a deep pit and was equipped with concrete side partitionings. In each pen there was one nipple waterer to allow ad libitum access to water. Standard farrowing records were recorded by farm personnel.

A grain sorghum-soybean meal gestation diet was fed to all sows and gilts, but with either 2 or 6 feedings per day (Table 2.1). Feed drops were set to provide 2.50 kg of feed per sow per day and 2.05 kg of feed per gilt per day. All feed for sows and gilts was dropped onto the solid concrete portion of the floor. Feed drops were scheduled to drop twice (07:00 and 15:30) or six times per day (07:00, 07:30, 08:00, 15:30, 16:00, and 16:30 hours, respectively). The time intervals were chosen because Woodworth (2002) determined that blood glucose and insulin peaked at approximately 30 min after consumption of a meal. Therefore, it was hypothesized that if the more dominant sows consumed the first meal they should have a greater sense of satiety by the time when the second and third feeding occurred. Feed drops were set at the beginning of the trial and adjusted if a sow or gilt was removed from the trial. To accommodate the amount of feed needed per day there were two feed drops per sow pen. For the gilts from d 0 to 42 there were three feed drops per pen and five feed drops per pen from d 42 to farrowing. Feed drops used were the Accu-Drop Feed Dispenser (Automated Production Systems, Assumption, IL).

Sow and gilt aggressiveness during gestation period was determined by visually scoring lesions on the total body and vulva. All visual scores were adapted from Zurbrigg (personal communication). Total body lesion scores were determined from a scale: 1 = no blemishes to some reddening or calluses, 2 = less then 10 scratches or 5 small cuts, 3 = more then 10 scratches or 5 small cuts, and 4 = most or whole area covered with scratches/wounds with little or no untouched skin. Visual scoring of the vulva was determined from a scale: 1 = no obvious wounds, 2 = slight laceration, 3 = severe lacerations observed, and 4 = sow with severe laceration and portions of the vulva absent. Structural integrity for sows and gilts was performed by visual scoring of the feet and legs. Visual scores for mobility were determined from a scale: 1 = no lameness observed in front or rear legs, 2 = animals with slight structural and/or movement problems, and 3 = sows/gilts with severe structural problems and unable to get up or walk. Hoof integrity scores were determined on a scale: 1 = no obvious lesions or cracks, 2 = animals with slight lesions on their foot pad and/or between toes, and 3 = sows with severe hoof cracking and lesions on the foot pad and/or between toes. Lesion scores were recorded on d 1 (before mixing) and every 14 d until farrowing.

Behaviors were video recorded for 96 h consecutively between d 50 and 60 of gestation. Sow behavior was observed using the Observer 5.1 behavior program (Noldus, Leesburg, VA) which allowed the duration of behaviors to be averaged for each observation to determine the percentage of time spent conducting each behavior. The analyses of behaviors were averaged over the 24-h behavior observation period. Behavior videos were blocked by time and 4 of the 13 pens per treatment were randomly selected for observations. The recorded behaviors were adapted from Dailey and McGlone (1997) and were drinking, eating, oral-nasal-facial (**ONF**), sitting, standing, lying, and antagonistic (behavior indicative of social conflict). The total active behaviors were calculated by subtracting lying behavior from the sum of all behaviors. Standing behavior was defined as having taken place when the animal adopted an upright position with all legs supporting the body. Lying was defined to involve contact of the body with the ground and the legs not supporting the body. Sitting behavior was defined as when the hindquarter portion of the body was in contact with the ground and support of body weight by front legs. Feeding behavior was when the pig was standing and with its head down on the solid concrete floor. Drinking behavior was defined as when pigs pressed their nose against the nipple waterer. Antagonistic was defined as physical encounters between at least two pigs. Oral-nasal-facial behavior was defined as belly-nosing, rubbing, sniffing, or licking of their pen mates.

Vocalization of sows was recorded using an Extech Model 407764 (Waltham, MA) data logging sound level meter. The data logger was set to a frequency weighting ‘A’ mode which responds like the human ear (boosting and cutting the noise amplitude over the frequency spectrum). The ‘A’ weighting mode is typically used for environmental measurements, OSHA regulatory testing, law enforcement, and workplace design. The meter was also set to slow mode (meter responds in 500 ms) to monitor a sound source that has a reasonably consistent noise level or to average quickly changing levels. Decibel readings at 1 min intervals are determined by using a sound level meter. The sound meters were placed approximately 0.15 m from the feed drop and 1 m above the feeding area. A directional cone was attached to the microphone to decrease extraneous noise from adjacent pens. Vocalization was not measured in gilts due to the combining of pens and movement to another facility on d 42.

Statistical Analysis.

Chi-square analysis was used to determine differences in the proportion of gilts and sows removed from the trial. Data were analyzed as a randomized incomplete block design using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Blocks were based on breeding time, and pen served as the experimental unit for performance and welfare response criteria. Blocks in the vocalization and behavior observations were based on time of recording. The model included the fixed effect of treatment and the random effect of block.

RESULTS

Feeding frequency did not influence ($P < 0.93$; Table 2.2) total sow removal or the proportion of sows removed for reproductive failure. Although relatively few sows were removed for structural problems, they were all on the twice per day feeding frequency leading to a higher ($P < 0.07$) removal rate for structural problems for sows fed twice per day than sows fed six times per day. In gilts, there was no influence ($P < 0.31$) of feeding frequency on removal from the trial because of reproductive failure or structural problems.

In sows, increasing feeding frequency from two to six times a day had no effect ($P < 0.32$) on overall gain, ADG, and backfat change (Table 2.3). Initial and final P2 backfat were not different ($P < 0.85$ and $P < 0.95$) among sows fed two or six times a day. Backfat gain (3.3 mm) was similar ($P < 0.96$) for sows on both feeding treatments. Sow weight variation increased from the beginning of gestation (CV of 11 and 12%, respectively) to the end of gestation (CV of 18 and 19%, respectively), but was not influenced ($P < 0.99$) by treatment.

In gilts, increasing the feeding frequency from twice to six times a day did not affect weight gain ($P < 0.12$) from d 0 to 42 of gestation (Table 2.4). However, there was a trend ($P < 0.07$) for gilts fed six times a day to have a greater ADG and therefore gain more weight from d 0 to 42 (12 vs. 15 kg) when compared with gilts fed twice a day. There were no differences ($P < 0.45$) in weight gain from d 42 of gestation until farrowing. Thus, final weight was similar ($P < 0.62$) for the two feeding frequencies.

There was no difference ($P > 0.10$) in initial weight variation for gilts; however, d 42 weight variation was greater ($P < 0.04$) for gilts fed six times a day. The greater variation may be because of the increase in ADG for gilts fed six times per day. The increased variation at transfer at d 42 was also observed in final weights ($P < 0.10$) before farrowing.

From d 0 to 42, gilts fed six times a day gained P2 backfat (0.37 mm) while gilts fed twice per day lost backfat (0.28 mm) resulting in 1 mm difference ($P < 0.09$) on day 42. From day 42 to the end of gestation, all gilts lost approximately 1 mm, but the difference observed on day 42 was maintained until the end of the gestation period. Among sows or gilts there were no difference ($P > 0.10$; Table 2.5) in number born alive, stillbirths, or mummies when feeding either twice or six times a day during gestation.

In sows, aggressiveness, as determined by visual scores of skin and vulva lesions, was greater ($P < 0.01$ and 0.04, respectively) when fed twice a day versus gestating sows fed six times a day (Table 2.6). Gestating sows fed six times a day experienced less ($P < 0.01$ and 0.02, respectively) structural problems with feet and legs and hoofs as measured by higher visual scores. It must be noted; however, that all scores were low indicating relatively few skin and vulva lesions or structural problems for either treatment. In gilts there were no differences ($P > 0.10$) observed for skin or vulva lesions or leg and hoof scores during the d 0 to 42 period or from d 42 to farrowing. Increasing the feeding frequency from two to six times a day increased the time spent standing ($P < 0.02$), feeding ($P < 0.02$), and ($P < 0.07$) the overall activity level of sows (Table 2.7). Vocalization was greater in the two hour period around the morning ($P < 0.07$) and afternoon ($P < 0.01$) feeding periods for sows fed six times a day versus sows fed twice a day (Table 2.8). As demonstrated in Figures 2.1 and 2.2, vocalization increased with each feeding and returned to baseline values. Sows fed six times per day had three distinct vocalization peaks during each feeding period indicating that they were more active over the feeding period.

DISCUSSION

Because group housing allows sows to exhibit increased social behavior and locomotion, and provides separate lying and dunging areas, it is often cited as being more favorable for the welfare status of the animal (van Putten and van de Burgwal, 1990). However, Kirkden and Pajor (2006) suggested that the increased social contact and space offered by a group pen was not important to previously stall-housed gestating sows. There also are major disadvantages to a group-housed system such as: increased weight variation between sows of different social hierarchy, the high incidence of lameness, and increase in skin and vulva damage (Task Force Report, 2005). Douglas et al. (1998) states the feeding regimen strongly influenced indicators of feeding motivation and arousal. The conventional diet in modern North American farms is concentrated in nutrients and although it is sufficient for good health and performance, it might not fulfill other needs of the sow, because the small amount of food is unlikely to give a feeling of satiety (Lawrence et al., 1988). Also sows normally eat as a group, but the amount of floor space available for feeding often decreases as the number of sows increase in a group setting. When the area of feeding is restricted, pigs tend to eat more quickly (Gonyou and Lou, 1996).

This eating behavior may lead to sow frustration and cause an increase of aggressiveness among "boss sows". This dominant status may be advantageous for sows in group housing pens. Brouns and Edwards (1994) reported that sows at the bottom of the hierarchy gained less weight than high ranking group members when fed once a day.

In this study, feeding frequency did not affect ADG, backfat change, or weight variation of group housed gestating sows. In a companion study using finishing pigs as a model, we also observed an increase in ADG with multiple feedings (6 vs 2 times daily; Schneider et al., unpublished data). The increase in ADG may be related to spreading out the nutrient load by increasing the feeding frequency which has been shown to improve nutrient utilization (Jenkins et al., 1980; Jenkins et al., 1989). In gilts, feeding six times per day tended to increase ADG and backfat from d 0 to 42. The increased backfat was maintained until farrowing, but final weight was similar at the end of gestation. The lack of differences in final weight was not surprising because gilts and sows on both treatments were fed the same total quantity of feed each day. The greater feeding frequency (six times per day) was hypothesized to reduce variation in weight gain; however, this did not occur. The more aggressive "boss" sows were expected to consume a greater portion of feed at the first morning and afternoon feedings and then allow more submissive sows to consume more feed at the second and third feedings. After the initial morning and afternoon meal, sows that consumed feed should have had a spike in blood glucose and insulin (Woodworth, 2002), which should have induced a greater sense of satiety by the time when the second and third feeding occurred. In reality, variation in final weight increased numerically in both sows and gilts when feeding frequency was increased suggesting that more aggressive sows may have been able to consume more total feed instead of less.

According to the Task Force Report (2005) there are few peer-reviewed reports that compare feeding methods on production measures of sows in housing systems; with the majority comparing sow productivity in group-housing versus in gestation stalls or tethers. Geverink et al. (2004) suggested that group-housed gilts showed greater energy metabolism and decreased energy requirements for maintenance when compared to gilts housed in gestation stalls. This may be caused by the greater ME_m in stall-housed pigs that is due to stress (Schrama et al., 1997). Furthermore, Hulbert and McGlone (2006) hypothesized that because group-housed sows may huddle together to conserve heat they might be fed slightly less feed than crated sows to maintain the same body condition. Hulbert and McGlone (2006) compared drop feeding versus a trickle feeding method in group-housed sows and found no significant difference in farrowing weight. However, the sows fed from the trickle feeding method were approximately 8 kg lighter at farrowing.

There were no differences in reproductive performance for sows or gilts fed either treatment; except for a trend for sows fed twice a day to farrow more total number of pigs. Feeding frequency was not expected to have a large impact on reproductive performance because increasing the feeding frequency was not thought to dramatically increase stress which may negatively affect reproductive performance (Norman et al., 1994; Varley and Stedman, 1994).

Sows fed six times per day had lower skin and vulva lesion scores and leg/feet and hoof scores than sows fed twice per day; however, there were no differences in gilts. Lower skin and vulva lesions are an indication that fewer fights and subsequent injuries occurred in the sows fed six times per day. However, the differences between treatments were relatively small. The low skin and vulva lesion scores are most likely results from the stable pen environment and established social order after mixing (Mendl, 1995). Sows fed six times per day were expected to have fewer hoof lesions because there should have been less feed impacted in hooves of sows fed six times per day because of the lower amount of feed on the concrete at any one time. Sows fed six times a day were more active during the feeding period, as measured by vocalization and video observation, versus sows fed twice a day. The increase in activity level in sows fed six times a day was related to the increase in time spent standing and feeding and the reduction in time spent lying. Although the behavior observation data associated with increasing feeding time is limited, Hulbert and McGlone (2006) did not find a difference in any behavior observed in sows when fed from a drop or trickle feeding system. Conversely, Hessel et al. (2006) used a scan sampling method and reported an increase in the percentage of time spent feeding when feeding frequency was increased from 3 to 9 meals per day. However, when using a continuous observation method for a 2-h period over the morning feeding period there was no difference in the percentage of time spent feeding. Furthermore, Hessel et al. (2006) explained that continuous observations are more precise than a time sampling methods for a short-term behavior such as feeding. Thus, the welfare criteria demonstrate both positive (lower lesion and structural problem scores in sows) and negative (increased vocalization) responses to increasing the feeding frequency.

Determining the welfare status of gestating sows can be challenging because of complexities between different gestation housing environments and challenges quantifying measures of welfare. A common problem with group housing of gestating sows is a condition commonly known as “boss sow” syndrome. This occurs when dominant sows that are high on the social order consume more feed than desired at the expense of other sows in the group. In this project, we increased the feeding frequency from two to six times per day and spaced the feedings at a designed interval in an attempt to induce the sense of satiety of the aggressive sows and reduce variation in sow weight gain within each pen. Increasing feeding frequency did not improve overall weight gain, weight variation, reproductive performance, or overall removal rate of group housed gestating sows or gilts. There was a small reduction in skin and vulva lesions and structural scores, but an increase in vocalization for sows fed six times per day. Thus, increasing the feeding frequency from two to six times per day does not appear to have a dramatic negative or positive impact on performance or welfare of group housed gilts and sows.

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Table 2.1 Composition of diet (as-fed basis)

Item, %	
Sorghum	83.50
Soybean meal (46.5% CP)	13.00
Monocalcium P (21% P)	2.30
Limestone	1.05
Salt	0.50
Trace mineral premix[1]	0.15
Vitamin premix[2]	0.25
Sow add pack[3]	0.25
Total	100.00
Calculated analysis	
ME, kcal/kg	3,256
CP, %	13.50
Total lysine, %	0.60
Total threonine, %	0.55
Total tryptophan, %	0.16
TSAA, %	0.51
Analyzed composition	
CP, %	14.61
Total lysine, %	0.62
Total threonine, %	0.52
Total tryptophan, %	0.17
TSAA, %	0.49

[1]Premix provides potency levels of following nutrients per kg: Copper at 11 g, Iodine at 198 mg, Iron at 110 g, Manganese at 26 g, Selenium at 198 mg, Zinc at 110 g.

[2]Premix provides potency levels of following nutrients per kg: Vitamin A at 4,400,000 IU, Vitamin D at 660,000 IU, Vitamin E at 17,600 IU, Vitamin K at 1,760 mg, Vitamin B_{12} at 15 mg, Niacin at 19,800 mg, Pantothenic acid at 11,000 mg, Riboflavin at 3,300 mg.

[3]Sow add pack provides potency levels of the following nutrients per kg: Biotin at 88 mg, Folic acid at 660 mg, Pyridoxine at 1,980 mg, Choline at 220,000 mg, Carnitine at 19,800 mg, Chromium at 79 mg.

Table 2.2 Effect of feeding frequency on removal of gestating gilts and sows[1]

	Frequency of feeding per day		
Item	2	6	*P*-value (*P* <)
Reason for sow removal			
Open	11	17	0.93
Structural problems	4	0	0.07
Total	15	17	0.97
Reason for gilt removal			
Open	23	19	0.31
Structural problems	0	0	0.99
Total	23	19	0.31

[1]Data was analyzed as a chi-square

Table 2.3 Effect of feeding frequency on performance of gestating sows[1]

Item	Frequency of feeding per day 2[2]	6[3]	SE	*P*-value (*P* <)[4]
Gestation period				
Initial weight, kg	229	233	5.66	0.67
Final weight, kg	276	276	4.90	0.99
Gain, kg	47	44	2.73	0.36
ADG, kg	0.50	0.46	0.04	0.34
ADFI, kg	2.50	2.50	0.01	0.23
CV of initial weight, %	10.62	12.27	1.09	0.31
CV of final weight, %	14.85	17.22	1.52	0.20
Initial backfat, mm	16.04	15.96	0.32	0.85
Final backfat, mm	19.35	19.32	0.35	0.95
Backfat change, mm	3.30	3.32	0.38	0.96

[1]Each value is the mean of 13 replications with 8 sows per pen.
[2]Received feed at 07:00 and 15:30 h.
[3]Received feed at 07:00, 07:30, 08:00, 15:30, 16:00, and 16:30 h, respectively.
[4]Data was analyzed as a balanced incomplete block design with day on trial as a covariate.

Table 2.4 Effect of feeding frequency on performance of gestating gilts

Item	Frequency of feeding per day: 2[1]	6[2]	SE	*P*-value (*P* <)[3]
Gestation d 0 to 42[4]				
Initial weight, kg	174	177	2.13	0.31
Final weight, kg	186	191	2.49	0.17
Gain, kg	12	15	1.49	0.12
ADG, kg	0.27	0.36	0.03	0.07
ADFI, kg	2.05	2.05	0.01	0.23
CV of initial weight, %	10.35	10.66	0.84	0.72
CV of final weight, %	10.26	12.48	0.89	0.04
Initial backfat, mm	18.93	19.53	0.37	0.14
Final backfat, mm	18.75	19.72	0.50	0.09
Backfat change, mm	-0.28	0.37	0.48	0.22
Gestation d 42 until farrowing[5]				
Initial weight, kg	188	193	4.07	0.24
Final weight, kg	214	216	4.89	0.62
Gain, kg	26	24	3.50	0.45
ADG, kg	0.47	0.42	0.06	0.53
ADFI, kg	2.05	2.05	0.01	0.23
CV of initial weight, %	10.21	13.47	0.85	0.02
CV of final weight, %	10.39	15.12	2.20	0.10
Initial backfat, mm	18.96	20.12	0.57	0.06
Final backfat, mm	18.01	19.20	0.50	0.04
Backfat change, mm	-0.97	-1.13	0.51	0.76

[1]Received feed at 07:00 and 15:00 h.
[2]Received feed at 07:00, 07:30, 08:00, 15:30, 16:00, and 16:30 h, respectively.
[3]Data was analyzed as a balanced incomplete block design with days on trial as a covariate.
[4]Each value is the mean of 12 replications with 12 gilts per pen.
[5]Each value is the mean of 6 replications with 17 to 23 gilts per pen.

Table 2.5 Effect of feeding frequency on reproductive performance of gestating gilts and sows[1]

	Frequency of feeding per day			
Item	2	6	SE	*P*-value (*P* <)
Sow farrowing fecord				
Total number born	14.64	13.58	0.38	0.08
Number born alive	11.98	11.32	0.39	0.26
Stillbirths	1.78	1.64	0.18	0.58
Mummies	0.89	0.62	0.15	0.21
Gilt farrowing record				
Total number born	14.22	14.39	0.39	0.75
Number born alive	11.15	11.37	0.31	0.62
Stillbirths	1.80	1.46	0.16	0.17
Mummies	1.28	1.56	0.27	0.42

[1]Reproductive performance was recorded by farm personnel and accessed via PigChamp® (Ames, IA) datatbase.

Table 2.6 Effect of feeding frequency on aggressiveness and soundness scores of gestation gilts and sows[1]

	Frequency of feeding per day			
Item	2	6	SE	*P*-value (*P* <)
Sows				
Aggressiveness				
Skin[2]	1.51	1.34	0.04	0.01
Vulva[2]	1.08	1.03	0.02	0.04
Structure				
Feet/Leg[3]	1.21	1.12	0.03	0.01
Hoof[3]	1.05	1.01	0.01	0.02
Gilts				
d 0 to 42				
Aggressiveness				
Skin[2]	1.36	1.37	0.03	0.82
Vulva[2]	1.06	1.06	0.01	0.94
Structure				
Feet/Leg[3]	1.03	1.03	0.01	0.75
Hoof[3]	1.01	1.00	0.01	0.24
d 42 to farrowing				
Aggressiveness				
Skin[2]	1.22	1.27	0.04	0.22
Vulva[2]	1.12	1.12	0.01	0.92
Structure				
Feet/Leg[3]	1.09	1.11	0.01	0.12
Hoof[3]	1.04	1.04	0.01	0.86

[1]Aggressiveness and structure scores were taken at d 0 and every 14 d thereafter until sows and gilts were moved into the farrowing house.
[2]Skin and vulva lesion scores ranged on a scale of 1 to 4.
[3]Feet/leg and Hoof scores ranged on a scale of 1 to 3.

2.7 Effect of feeding frequency on the percentage of time spent conducting each behavior[1,2]

Behavior	Frequency of feeding per day 2	Frequency of feeding per day 6	SE	*P*-value (*P* <)
Agonistic	0.02	0.02	0.01	0.99
Active	4.43	5.13	0.25	0.07
Oral-nasal-facial	2.53	2.63	0.17	0.65
Lie	95.58	94.88	0.25	0.07
Stand	1.05	1.51	0.09	0.02
Sit	0.55	0.57	0.09	0.84
Drink	0.06	0.07	0.01	0.49
Feed	0.23	0.36	0.03	0.02

[1]Behavior observations were recorded for 4 consecutive days in each treatment.
[2]Active behavior was determined by subtracting lying behavior from the sum of all behavior.

Table 2.8 Effect of feeding frequency on decibel level measured over a 2 h period[1]

Item	Frequency of feeding per day		SE	P-value (P <)
	2	6		
Feeding Time				
AM	8,458	8,540	41.4	0.07
PM	8,348	8,906	41.4	0.01

[1]Area under the curve is the sum of the decibel level measured over a two hour sampling period.

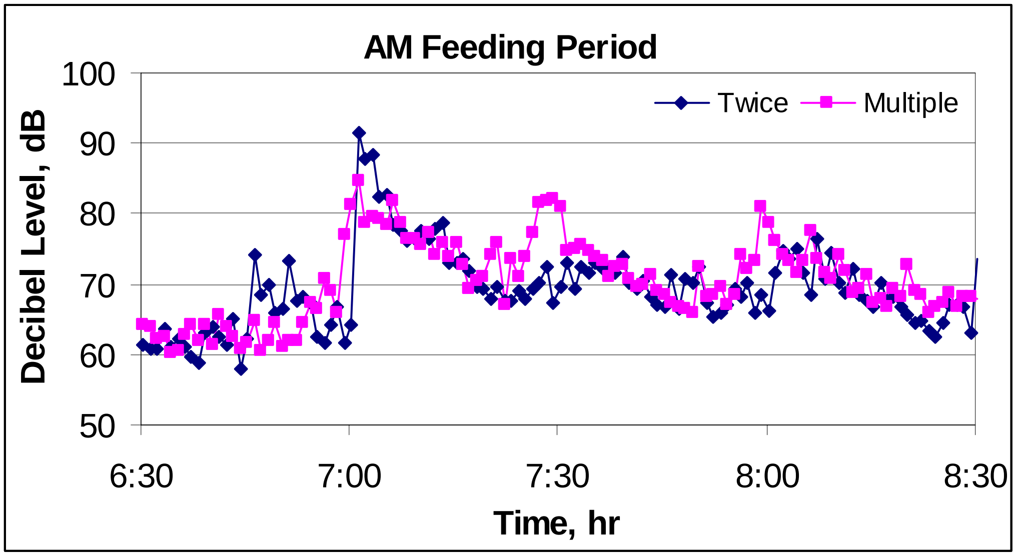

Figure 2.1 Diagram of the decibel levels measured in a two hour period over the morning feeding period. Feed drops were scheduled to drop twice (07:00 and 15:30) or six times per day (07:00, 07:30, 08:00, 15:30, 16:00, and 16:30 hours, respectively).

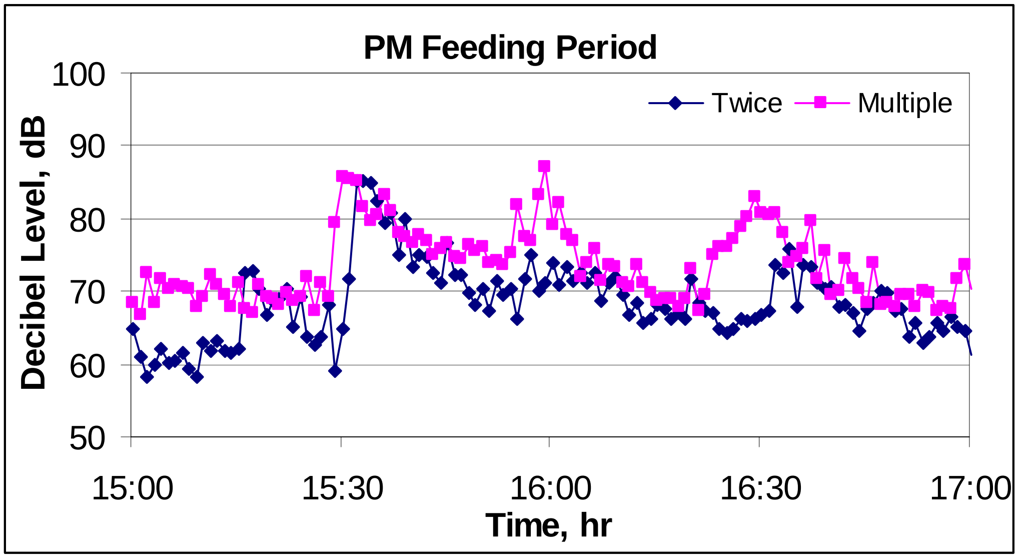

Figure 2.2 Diagram of the decibel levels measured in a two hour period over the afternoon feeding period. Feed drops were scheduled to drop twice (07:00 and 15:30) or six times per day (07:00, 07:30, 08:00, 15:30, 16:00, and 16:30 hours, respectively).

CHAPTER 3 - Effect of restricted feed intake on finishing pigs weighing between 68-114 kg fed twice or six times daily

ABSTRACT: Two 42-d trials and two 28-d trials were conducted to evaluate the effect of a restricted feed intake and feeding frequency (2 or 6 times daily) on the performance of pigs weighing between 68 to 114 kg (initially 66.9 kg in Exp. 1; 70.1 kg in Exp. 2; 70.8 kg in Exp. 3; and 70.7 kg in Exp. 4). In all experiments, pigs were housed in 1.8 × 3.1 m pens with half-solid and half-slatted concrete flooring and with one nipple waterer. Pigs were fed a corn-soybean meal-based diet formulated to 1.15% TID lysine and 3,294 kcal of ME/kg. In Exp. 1 to 3, energy and lysine were supplied to pigs to target an average growth rate of 0.80 kg/d based on NRC (1998) calculations. In Exp. 4, the diet was supplied to pigs to target growth rates of 0.80 kg/d (low feed intake) or 0.95 kg/d (high feed intake) based on NRC (1998) values to determine if the amount of energy above maintenance and feeding frequency had an effect on performance. Pigs were fed by dropping similar amounts of feed daily, either 2 (07:00 or 14:00) or 6 times (3 meals within 2 h at AM and PM feedings) per day, by an Accu-Drop Feed Dispenser® (AP Systems, Assumption, IL) onto the solid concrete flooring. Data from all experiments were analyzed as a complete randomized design using the MIXED procedure of SAS. In Exp. 1 and 2, increasing the feeding frequency of pigs fed a restricted diet from 2 to 6 times per day increased ($P < 0.02$) ADG and G/F. Increasing the feeding frequency increased ($P < 0.05$) the duration of time spent feeding and standing, and reduced lying time. In Exp. 3, a third treatment was included in addition to those used in Exp. 1 and 2 to determine whether the improvements in performance were due to decreased feed wastage. This treatment was designed to minimize feed wastage by dropping feed closer to the floor in pigs fed 2 times per day. Pigs fed 6 times per day had improved ($P < 0.05$) ADG and G/F compared to either treatment fed 2 times per day. There was no difference ($P > 0.05$) in performance between pigs fed 2 times per day when feed was dropped from the feed drop or by the modified method to reduce feed wastage. In Exp. 4,

increasing the feeding frequency from 2 to 6 feeding periods increased ($P < 0.01$) ADG and G:F for pigs fed a low level of feed intake and tended to increase ($P < 0.06$) ADG and improved ($P < 0.05$) G:F for pigs fed a high level of feed intake. In conclusion, these studies indicate that increasing the frequency of feeding from 2 to 6 times a day improves pig performance compared with feeding 2 times per day.

Keywords: feeding frequency, growth, pigs, restricted intake

INTRODUCTION

These experiments were initiated based on earlier data of Schneider (2007) where gestating gilts and sows were fed 2 or 6 times per day. Results from this earlier trial showed that gilts fed 6 times versus 2 times a day during the first 42 d of gestation had a tendency for increased ADG; however, this response was not found in sows. Therefore, finishing pigs were used as a model to confirm these earlier results with gestating gilts.

Sow longevity is the primary economic indicator of efficient piglet production. Most sow longevity research has concentrated on feed intake and backfat loss during lactation (Serenius et al., 2006). However, little data is available on the effect of gilt performance on longevity (Rozeboom et al., 1996). Current gilt development recommendations suggest that they reach their second estrous at a minimum BW of approximately 135 kg before they are eligible for breeding, while some producers and breeding stock companies desire that gilts also reach a minimum age (Young, 2004). In high health situations, gilts may be past the 135 kg BW target before expressing their second estrous or reaching the minimum age set by the breeding stock supplier. This may affect their lifetime performance in the breeding herd (Foxcroft et al., 2005). Ultimately, heavier gilts at breeding increase their gestation maintenance requirement (NRC, 1998). This increase in physical size may dictate wider stall dimensions if welfare standards are to be maintained in stalls that do not obstruct sow movements (McGlone et al., 2004). Restricting feed intake to moderate growth rate in developing gilts would help prevent excessively heavy gilts. However, restricting feed intake during the growing phase is extremely difficult due to design of most modern facilities because they typically use pens for developing replacement gilts. Therefore, the objective of this study was to determine the effects of restricting feed intake of pigs fed either 2 or 6 times per day in a group housed environment.

MATERIALS AND METHODS

General.

Procedures used in these experiments were approved by the Kansas State University Animal Care and Use Committee. All experiments were conducted at the Kansas State University Swine Research and Teaching Center. Each pen was 1.8 × 3.1 m and contained half solid and half slatted flooring with a deep pit and one curtain side (Figure 3.1). Each pen was equipped with solid side partitioning gates over the solid flooring between pens to prevent feed transfer. In each pen there was one nipple waterer to allow ad libitum access to water. The experimental diet was a corn-soybean meal diet formulated to 1.15% TID lysine and 3,287 ME kcal/kg (Table 3.1). If a pig was removed from the study for any reason, the pig weight and pen feed consumption to date was recorded and feed drops were adjusted to accommodate changes in the feeding calculation. Feed was measured and delivered using an Accu-Drop Feed Dispenser (Automated Production Systems, Assumption, IL) which was located approximately 1.8 m from the solid concrete floor where the feed was consumed.

Experiment 1 and 2.

A total of 320 pigs (Exp. 1, initial BW = 67.3 kg, n =160; Exp. 2 initial BW = 70.1 kg, n = 160) were used in a 42-d growth assay to determine the effects of a restricted feed level either two or six times per day on growth performance. Pigs were separated by sex and blocked by BW to 16 pens with 10 pigs each. There were 4 pens of barrows and 4 pens of gilts per treatment for a total of 8 replications. Pigs were provided their daily feed allotment in two or six meals. In Exp. 1, Pigs receiving two meals were fed at 07:00 and 15:30 h. Pigs fed six times per day were fed at 07:00, 07:30, 08:00, 15:30, 16:00, and 16:30 h. In Exp. 2, Pigs receiving two meals were fed at 07:00 and 15:00 h. Pigs fed six times per day were fed at 07:00, 08:00, 09:00, 15:00, 16:00, and 17:00 h. All pigs were fed a restricted feed level that was calculated to allow a gain of 0.80 kg/day based on NRC (1998) values. In these experiments the amount of feed given to a pen was determined every 14 d based on the overall average weight of pigs. Pigs were weighed individually on d 0, 14, 28, and 42 to determine ADG, G:F, and CV for individual pig weight gain within the pen.

Experiment 3.

A total of 150 pigs (initial BW = 70.8) were used in a 28-d growth assay to determine the effects of feeding a restricted feed level either two or six times per day on growth performance and to determine whether feed wastage was the reason for the difference in performance found in Exp. 1 and 2. Pigs were assigned to one of three treatments with 15 pens of 10 pigs each. There were a total of 5 replications per treatment. The treatments consisted of feeding times with pigs fed six times daily, pigs fed twice daily, and pigs fed twice daily with an modified feeding system to attempt to limit feed wastage (**2 Modified**; Figure 3.2). Our theory was that a large amount of feed was being dropped onto the back of the pigs which increased feed wastage in pigs fed 2 times per day. The 2 modified treatment consisted of using PVC piping and flex-tubing to place the daily feeding allotment on the concrete flooring, also 5.08 × 15.24 cm boards were attached in front of the partial slats. Pigs were provided their daily feed allotment in two or six meals. Pigs receiving two meals were fed at 07:00 and 15:00 h. Pigs fed six times per day were fed at 07:00, 08:00, 09:00, 15:00, 16:00, and 17:00 h. All pigs were fed a restricted feed level that was calculated to allow a gain of 0.80 kg/day based on NRC (1998) values. In these experiments the amount of feed given to a pen was determined every 14 d based on the overall average weight of pigs. Pigs were weighed individually on d 0, 14, and 28 to determine ADG, G:F, and CV for individual pig weight gain within the pen.

Experiment 4.

A total of 160 pigs (initial BW = 70.7 kg) were used in a 28-d growth assay to determine the effects of feed intake level fed either two or six times per day on pig growth performance. The pigs were separated by sex and randomly allotted by BW to 16 pens of 10 pigs each. There were a total of 4 replications per treatment. Feed was provided to pigs to target an average growth rate of 0.80 kg/day (low feed intake level) or 0.95 kg/day (high feed intake level) based on NRC (1998) values to determine if the amount of energy above maintenance and feeding frequency had an effect on performance. This study was conducted to determine if similar growth response would be seen in pigs fed 6 times a day on a diet that was closer to ad libitum intake. Pigs receiving two meals were fed at 07:00 and 15:00 h. Pigs fed six times per day were fed at 07:00, 08:00, 09:00, 15:00, 16:00, and 17:00 h. Pigs were weighed individually every 14 d to determine ADG, G:F, and CV for individual pig weight gain within the pen.

Behavioral Measures.

Behaviors were recorded continuously for 24 h using a digital video recorder on d 3 to 4, 15 to 16, 29 to 30, and 40 to 41 of Exp. 1 and 2. Behaviors were observed using the Observer 5.1 behavior program (Noldus, Leesburg, VA) which allowed the frequency and duration of behaviors to be averaged for the 24 h periods. Behavior videos were blocked by time and pens were randomly selected for observations. The behaviors were adapted from Dailey and McGlone (1997) and were recorded as time spent drinking, eating, oral-nasal-facial (**ONF**), sitting, standing, lying, or antagonistic (behavior indicative of social conflict). The total active behaviors were calculated by subtracting lying behavior from the sum of all behaviors.

Standing behavior was defined as having taken place when the animal adopted an upright position with all legs supporting the body. Lying was defined to involve contact of the body with the ground and the legs not supporting the body. Sitting behavior was defined as when the hindquarter portion of the body was in contact with the ground and support of body weight by front legs. Feeding behavior was when the pig was standing and with its head down on the solid concrete floor. Drinking behavior was defined as when pigs pressed their nose against the nipple waterer. Antagonistic was defined as physical encounters between at least two pigs. Oral-nasal-facial behavior was defined as belly-nosing, rubbing, sniffing, or licking of their pen mates.

Statistical Analysis.

The data from all experiments were analyzed as a randomized complete block design with pen as the experimental unit. The growth assay model included the fixed effect of treatment and the random effect of block. In Exp. 4, the data was organized as a 2 × 2 factorial and analyzed for the main effects of feed intake level and feeding frequency and the interaction of feed intake level × feeding frequency. There was no significant effect of sex in any of the experiments; therefore, all performance data within a treatment were pooled. The behavioral data was averaged over the 24 h period and represented as a percentage of behavioral actions throughout the recorded period. The model for the behavioral observations included the fixed effect of treatment and the random effect of pen and block. Analysis of variance was performed by using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC.).

RESULTS

Experiment 1.

Pigs receiving two meals were fed at 07:00 and 15:30 h. Pigs fed six times per day were fed at 07:00, 07:30, 08:00, 15:30, 16:00, and 16:30 h. Overall (d 0 to 42), pigs fed 6 times versus 2 times a day had increased ($P < 0.01$; Table 3.2) ADG and G:F. As expected, ADFI was not different ($P = 0.77$) due to the fact that similar amounts of feed were provided to both treatments. The CV for individual pig weight gain within the pen was not influenced ($P > 0.83$) by feeding frequency. Increasing the feeding frequency increased ($P < 0.03$; Table 3.3) the duration of time spent feeding, standing ($P < 0.01$), ONF ($P < 0.03$), and reduced ($P < 0.01$) the time spent lying. This resulted in an overall increase ($P < 0.01$) in activity level.

Experiment 2.

Pigs receiving two meals were fed at 07:00 and 15:00 h. Pigs fed six times per day were fed at 07:00, 08:00, 09:00, 15:00, 16:00, and 17:00 h. Overall (d 0 to 42), pigs fed 6 times versus 2 times a day had increased ($P < 0.02$; Table 3.4) ADG and G:F. Average daily feed intake was not influenced ($P > 0.91$) as expected because similar amounts of feed were provided in both treatments. The CV for individual pig weight gain within the pen was not influenced ($P > 0.45$) by treatments. Increasing the feeding frequency increased ($P < 0.01$; Table 3.5) the duration of time spent feeding, standing ($P < 0.01$), and reduced the time spent lying ($P < 0.01$). This resulted in an overall increase ($P < 0.01$) in activity level.

Experiment 3.

Pigs receiving two meals were fed at 07:00 and 15:00 h. Pigs fed six times per day were fed at 07:00, 08:00, 09:00, 15:00, 16:00, and 17:00 h. Overall (d 0 to 28), pigs fed 6 times a day had increased ($P < 0.05$; Table 3.6) ADG and G:F over pigs fed twice a day from either the modified feeders or directly from the feed drops. Average daily feed intake was not influenced ($P > 0.57$) as expected because similar amounts of feed was given to all treatments. The CV for individual pig weight gain within the pen was not influenced ($P > 0.36$) by treatments.

Experiment 4.

Pigs receiving two meals were fed at 07:00 and 15:00 h. Pigs fed six times per day were fed at 07:00, 08:00, 09:00, 15:00, 16:00, and 17:00 h. Overall (d 0 to 28), there tended to be a feed intake level × feeding frequency interaction observed for ADG ($P < 0.08$) and G:F ($P < 0.02$; Table 3.7 and 3.8). Increasing the feed intake level increased ($P < 0.05$) ADFI and CV for individual pig weight. Increasing the feeding frequency tended to increase ($P < 0.10$) CV for individual pig weight. Pigs fed 6 times per day at the low feed intake level had increased ($P < 0.01$) ADG while those fed the high feed intake level had a tendency for increased ($P < 0.06$) ADG versus those fed 2 times per day. Pigs fed both high and low feed intake levels had improved ($P < 0.05$) G:F when fed 6 times per day versus fed 2 times per day. Average daily feed intake was not influenced by feeding frequency for pigs fed the high feed intake level ($P > 0.26$) or low feed intake level ($P > 0.63$). This was expected because similar amounts of feed were provided within treatments. The CV for individual pig weight gain within the pen was not influenced by feeding frequency for the pigs fed the high feed intake level ($P > 0.15$) or low feed intake level ($P > 0.35$) treatments.

DISCUSSION

In these experiments, feeding six times increased ADG and improved feed efficiency versus pigs fed twice a day, even though the pigs were fed an equal amount of feed based on average weight to attain a specific growth rate. This may have been due to improved nutrient digestibility (de Haer and de Vries, 1993a) and change in basal metabolism (Sharma et al., 1973) associated with an increase in feeding frequency. Increasing feeding frequency has been shown to increase the flow of digestive enzyme production in the small intestine (Ruckebush and Bueno, 1976; Sissons and Jones, 1991; van Leeuwen et al., 1997). Botermans et al. (2000) found increasing the number of meals (1 vs. 12) increased protein output, chymotrypsin, and lipase activity (Hee et al., 1998). de Haer and de Vries (1993b) suggested that increasing feeding frequency increases pancreatic secretions and has a positive relationship with digestibility. Furthermore, this increase of exocrine pancreatic secretion was found to be independent of the amount of feed consumed (Botermans and Pierzynowski, 1999).

Another possible explanation to the increased performance is a response called the second-meal phenomenon (Jenkins et al., 1980). This phenomenon is thought to improve carbohydrate tolerance and reduce the insulin response by spreading the nutrient load over a longer period of time. Furthermore, the closeness of one meal to the next determined the glycemic response and potentially eliminates the extreme high and low glycemic peaks. The result is a smoother more controlled response, thus creating more efficient utilization. This hypothesis is used in human health studies that attempt to decrease the occurrence of diabetes by manipulating the frequency of meals. Lundin et al. (2004) has shown that diabetic patients improve their glucose tolerance when consuming an isocaloric diet over 10 versus three meals. Furthermore, Cohn (1964) found that increased meal frequency reduced total cholesterol, LDL cholesterol (Jenkins et al., 1989), and serum free fatty acids (Wolever, 1990) in human patients.

Regardless of the response method, in all studies increasing the feeding frequency from twice to six times a day increased ADG and improved G:F. Feed wastage in 2 times per day feeding was hypothesized to be responsible for the ADG response in Exp. 1 and 2. This was due to the potential wastage of feed that falls directly onto the pigs during feeding. Therefore, the modified treatment in Exp. 3 delivered feed directly to the floor, thus prevent feed from dropping on the pig. However, the growth performance of pigs fed six or two times per day mimicked the response found in Exp. 1 and 2. Thus, it was concluded that the ADG response was not due to differences in feed wastage between treatments. This is further confirmed with the consistent improvement in G:F, thus, indicating improved nutrient utilization.

These results were similar to those of Sharma et al. (1973) which revealed an influence of frequency of feeding on energy utilization. In their study, they found that pigs fed multiple times had higher maintenance requirements, but were also more efficient converters of the available ME above maintenance for tissue deposition. On the other hand, work by van Leeuwen et al. (1997) and Friend and Cunningham (1964) did not demonstrate differences in digestibility or performance between pigs fed the same total amount of feed in large meals or several small meals. Schneider (2007) tested the same feeding regimen in gestating gilts and sows. There was no difference in growth performance for gestating sows, but there was an increase in ADG for gestating gilts from d 0 to 42 of gestation. The reason for the treatment effect in the present experiments and in the first period of gestating gilts may be related to the amount of energy available above maintenance requirements.

After examining these results a question arose concerning the amount of energy above maintenance and it effects on performance. In Exp. 4, energy and lysine were supplied to pigs to target an average growth rate of 0.80 kg/day (low feed intake) or 0.95 kg/day (high feed intake) based on NRC (1998) values. The purpose of these dietary energy levels were to determine if similar growth response would be seen in pigs fed six times a day on a diet that was closer to ad libitum intake (low feed intake level = 2.1 times above maintenance; high feed intake level = 2.7 times above maintenance). Improvements in ADG and G:F were reported for both feed intake levels as feeding frequency increased from 2 to 6 times daily. However, those fed the lower feed intake level had larger improvements than those fed the higher feed intake level.

An area of concern with the present studies may be related to the discrepancies in the predicted growth rate versus the actual growth response. In Exp. 1, 2, and 3, all pigs were fed to gain 0.80 kg/d using the NRC (1998) calculations based on BW. However, the ADG responses in our growth assays were under those predicted by the NRC (1998) calculations and may be due to environment, genetics, or inaccuracies in the NRC (1998) equations. The reasons behind the inaccuracies in ADG using NRC (1998) may be due to an underestimated maintenance requirement, feed intake was based on initial period (d 0 or the 14 d period) weight for maintenance, and overestimation of FFL gain when limiting energy intake.

Behavior observations revealed that increasing the feeding frequency from 2 to 6 times per day increased active behavior and decreased the amount of time spent lying. Similar results were seen when comparing an increase in feeding frequency of growing-finishing pigs fed a liquid diet by Kracht et al. (1982) when pigs were fed 2 vs. 3 times per day and Hessel et al. (2006) when pigs were fed 3 vs. 9 times per day. The amount of time spent feeding was increased for pigs fed 6 times a day versus pigs fed 2 times a day. This is similar to the results from Hessel et al. (2006) in which pigs fed 9 times per day spent more time feeding than pigs fed 3 times per day. However, Hulbert and McGlone (2006) did not report a difference in the duration of feeding behaviors in sows fed either by a drop or trickle feeding method.

According the Baxter (1986), 90% of all aggressive interactions between pigs occur during feeding as a direct result of competition. Time budgets of agonistic behavior were not influenced by feeding frequency in the current study. However, Hessel et al. (2006) found an increase in agonistic behavior for pigs fed 9 times daily versus pigs fed 3 times daily in the growing-finishing period. Also, pigs fed 9 times were more likely to have a higher injury score for the caudal part of their body. The differences in behavior in our studies versus Hessel et al. (2006) may be due to diet and pen effects. Hessel et al. (2006) restrictively fed pigs a liquid whey diet in a trough, while the current studies fed pigs a corn-soybean meal based diet on a solid concrete floor.

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Table 3.1 Composition of experimental diet (as-fed basis) (Exp. 1 to 4)

Item	Diet, %
Corn	63.14
Soybean meal (46.5% CP)	33.26
Monocalcium P (21% P, 18% Ca)	1.40
Limestone	1.25
Salt	0.35
Trace mineral premix[1]	0.20
Vitamin premix[2]	0.15
L-lysine HCL	0.15
L-threonine	0.05
DL-methionine	0.05
Total	100.00
Calculated analysis	
ME, kcal/kg	3,287
CP, %	21.0
Total lysine, %	1.29
Ca	0.87
Available P	0.37
TID amino acids, %	
Lysine	1.15
Threonine	0.74
Isoleucine	0.79
Leucine	1.66
Analyzed composition, %	
CP	21.05
Total Lysine	1.19
Total threonine	0.82
Total isoleucine	1.33
Total Leucine	0.84

[1]Premix provides potency levels of following nutrients per kg: Copper at 11 g, Iodine at 198 mg, Iron at 110 g, Manganese at 26 g, Selenium at 198 mg, Zinc at 110 g.

[2]Premix provides potency levels of following nutrients per kg: Vitamin A at 4,400,000 IU, Vitamin D at 660,000 IU, Vitamin E at 17,6000 IU, Vitamin K at 1,760 mg, Vitamin B_{12} at 15 mg, Niacin at 19,800 mg, Pantothenic acid at 11,000 mg, Riboflavin at 3,300 mg.

Figure 3.1 Picture represents the pen design for pigs fed 2 or 6 times per day in all experiments.

Figure 3.2 Picture represents the Modified treatment that delivered feed directly onto the concrete flooring (Exp. 3).

Table 3.2 Effect of feeding frequency on energy restricted diet on performance of finishing pigs (Exp. 1)[1]

Item	Frequency of feeding per day		SE	*P*-value (*P* <)
	2[2]	6[3]		
d 0-42[4]				
ADG, g	606	683	15.74	0.01
ADFI, g	1,677	1,677	0.62	0.77
G:F	0.36	0.41	0.01	0.01
CV of gain, %	4.62	4.52	0.23	0.83

[1]Each value is the mean of eight replications with 10 pigs (initially 66.9 kg) per pen.
[2]Received feed at 07:00 and 15:30 h.
[3]Received feed at 07:00, 07:30, 08:00, 15:30, 16:00, and 16:30 h, respectively.
[4]Feed drops were adjusted every 14 d based on the average weight of pigs.

3.3 The duration of behaviors expressed as a percentage of time over 24 h (Exp. 1)[12]

Behavior	Frequency of feeding per day: 2[3]	6[4]	SE	*P*-value (*P* <)
Agonistic	0.26	0.28	0.06	0.51
Active[5]	12.20	14.35	0.19	0.01
Oral-nasal-facial	1.30	1.65	0.09	0.03
Lie	87.80	85.65	0.19	0.01
Stand	4.70	5.70	0.12	0.01
Sit	0.62	0.67	0.06	0.44
Drink	0.31	0.33	0.03	0.40
Feed	5.03	5.73	0.16	0.03

[1]Each value is the mean of eight replications with 10 pigs (initially 66.9 kg) per pen.
[2]Values for the behavior observations were averaged over a 24 h period for a combination of 4 total days per treatment.
[3]Received feed at 07:00 and 15:30 h.
[4]Received feed at 07:00, 07:30, 08:00, 15:30, 16:00, and 16:30 h, respectively.
[5]Active behavior was determined by subtracting lying behavior from the sum of all behavior

Table 3.4 Effect of feeding frequency on energy restricted diet on performance of finishing pigs (Exp. 2)[1]

	Frequency of feeding per day			
Item	2[2]	6[3]	SE	*P*-value (*P* <)
d 0-42[4]				
ADG, g	504	623	28.52	0.02
ADFI, g	1,728	1,728	0.54	0.91
G:F	0.29	0.36	0.02	0.02
CV of gain, %	5.18	4.77	0.37	0.45

[1]Each value is the mean of eight replications with 10 pigs (initially 70.1 kg) per pen.
[2]Received feed at 07:00 and 15:00 h.
[3]Received feed at 07:00, 08:00, 09:00, 15:00, 16:00, and 17:00 h, respectively.
[4]Feed drops were adjusted every 14 d based on the average weight of pigs.

3.5 The duration of behaviors expressed as a percentage of time over 24 h (Exp. 2)[12]

Behavior	Frequency of feeding per day: 2[3]	6[4]	SE	*P*-value (*P* <)
Agonistic	0.29	0.31	0.03	0.60
Active[5]	12.46	14.88	0.08	0.01
Oral-nasal-facial	1.38	1.50	0.06	0.15
Lie	87.55	85.12	0.08	0.01
Stand	5.15	6.08	0.13	0.01
Sit	0.61	0.63	0.03	0.55
Drink	0.31	0.32	0.01	0.45
Feed	4.73	6.05	0.15	0.01

[1]Each value is the mean of eight replications with 10 pigs (initially 66.9 kg) per pen.
[2]Values for the behavior observations were averaged over a 24 h period for a combination of 4 total days per treatment.
[3]Received feed at 07:00 and 15:30 h.
[4]Received feed at 07:00, 07:30, 08:00, 15:30, 16:00, and 16:30 h, respectively.
[5]Active behavior was determined by subtracting lying behavior from the sum of all behavior.

Table 3.6 Effect of feeding frequency on energy restricted diet on performance of finishing pigs (Exp. 3)[1]

Item	Frequency of feeding per day			SE
	2 Modified[24]	2[2]	6[3]	
d 0-28[5]				
ADG, g	509[a]	518[a]	608[b]	26.56
ADFI, g	1,657	1,658	1657	1.99
G:F	0.31[a]	0.31[a]	0.37[yb]	0.02
CV of gain, %	4.01	4.46	4.75	0.55

[a,b]Values within a row lacking a common superscript letter are different ($P < 0.05$).
[1]Each value is the mean of eight replications with 10 pigs (initially 70.8 kg) per pen.
[2]Received feed at 07:00 and 15:00 h.
[3]Received feed at 07:00, 08:00, 09:00, 15:00, 16:00, and 17:00 h, respectively.
[4]Pens fed the 2 modified treatment were fed twice daily with feed delivered directly onto the concrete floor.
[5]Feed drops were adjusted every 14 d based on the average weight of pigs.

Table 3.7 Effect of feeding frequency on energy restricted diet on performance of finishing pigs (Exp. 4)[1]

	Frequency of feeding per day			
Item	2[2]	6[3]	SE	*P*-value (*P* <)
d 0-28[4]				
Low feed intake[5]				
ADG, g	466	633	44.76	0.01
ADFI, g	1,610	1,610	1.25	0.26
G:F	0.29	0.39	0.02	0.01
CV of gain, %	4.62	4.24	0.27	0.35
High feed intake[6]				
ADG, g	635	709	44.76	0.06
ADFI, g	2,048	2,047	1.25	0.63
G:F	0.31	0.35	0.02	0.05
CV of gain, %	4.12	3.53	0.27	0.15

[1]Each value is the mean of four replications with 10 pigs (initially 70.7 kg) per pen.
[2]Received feed at 07:00 and 15:00 h.
[3]Received feed at 07:00, 08:00, 09:00, 15:00, 16:00, and 17:00 h, respectively.
[4]Feed drops were adjusted every 14 d based on the average weight of pigs.
[5]Pigs were fed to gain 0.80 kg/d based on NRC (1998) values.
[6]Pigs were fed to gain 0.95 kg/d based on NRC (1998) values.

3.8 Probability of the main effects and interaction (Exp. 4)[1]

	P-value (*P* <)		
Item	Feed intake level	Feeding frequency	Feed itake level × Feeding frequency
ADG, g	0.01	0.01	0.08
ADFI, g	0.01	0.63	0.26
G:F	0.33	0.01	0.02
CV of gain, %	0.05	0.10	0.70

[1]Each value is the mean of four replications with 10 pigs (initially 70.7 kg) per pen.

CHAPTER 4 - Determining the accuracy of gestation feed drops

ABSTRACT: An experiment was conducted to determine the accuracy of three different styles of gestation feed drops (Econo, Accu, Ultra; Automated Production Systems, Assumption, IL). Each drop was tested at three different angles (90, 75, and 60°) from the feed line. Drops were attached to a 5 cm diameter feed line and feed was collected and weighed at settings of 0.91, 1.82, 2.73, 3.64, and 4.55 kg for the Econo and Accu feed drops. Due to the smaller feed storage capacity, settings of 0.91, 1.82, 2.73, and 3.64 kg were used for the Ultra feed drop. A single corn-soybean meal diet was used. The feed drops were blocked based on location on the feed line with one feed drop of each type randomly allotted within each of the five blocks (i.e., a block is represented by the first three openings in the feed line and one feed drop of each type was then randomized within the block). Two feed samples were collected at each feeder setting for a specific angle and weighed on a scale that allowed for a measurement to one hundredth of a kg. Data was analyzed as a split plot design with the feed drop as the whole plot and angle as the subplot; analysis of variance was performed using the PROC MIXED procedure of SAS. There was a drop type × angle × feed level interaction ($P < 0.01$) for the feed settings versus the actual amount dropped. The interaction was the result of the amount of feed dropped at each setting by the Econo drop being influenced more by the angle to the feed line than with the Accu or Ultra feed drops. At 90°, the relationship between the feeder setting (x) and actual quantity of feed dropped was best described by the regression equation (1.11x + 0.2438) for the Econo; (1.01x + 0.0715) for the Accu; and (1.01x + 0.2309) for the Ultra. At 75°, the regression equations were (1.05x - 0.1387) for the Econo; (1.00x + 0.057) for the Accu; and (1.01x + 0.1559) for the Ultra. At 60°, the regression equations were (0.69x – 0.076) for the Econo; (0.99x – 0.2493) for the Accu; and (0.95x + 0.0255) for the Ultra feed drop. The Accu and Ultra feed drops had a lower ($P < 0.05$) slope and less change ($P < 0.05$) in slope and intercept when the angle to the feed line changed from 90 to 75° compared to the Econo, indicating they more accurately dropped the correct amount of feed. This study demonstrated that the Accu and Ultra feed drops are more accurate than the Econo feed drop.

Keywords: Feed, feed drop, gestation

INTRODUCTION

The use of individual gestation stalls or crates in environmentally controlled barns has generally become the accepted standard method for sow management (Barnett et al. 2001). Housing sows in stalls allows producers to have a direct control over the intake of sows and ultimately the overall composition and growth of the animal (Trottier and Johnston, 2001). Individual feed drops are used to provide a set amount of feed to each individual animal. These feed drops are made by several manufacturers and marketed in a variety of designs. However, information on the accuracy of individual feed drops has not been published. As a further complication to the question of accuracy of feed drops, the drops are installed and intended to be used when perpendicular (90° angle) to the feed line. Either during installation or after years of use, many drops are at angles of less than 90° from the feed line. However, the influence of the angle to the feed line on feed drop accuracy is not known. If in fact the angle influences drop accuracy, producers could utilize this information in equipment purchasing decisions and management of existing feed drops. Thus, the objective of this experiment is to determine the accuracy of three different styles of individual drop feeders when they were fitted at angles of 90, 75, and 60°.

MATERIALS AND METHODS

This experiment was conducted at the Kansas State University Swine Research and Teaching Center. The experimental diet was a corn-soybean meal diet formulated to 1.15% TID lysine, 21% crude protein and 3,287 kcal of ME/kg (Table 4.1). All feed drops were purchased from Automated Production Systems (AP, Assumption, IL) and attached to a 5 cm feed line. The feed drops used in this experiment were the Ultra, the Econo, and the Accu feed drop (Figure 4.1).

The feed drops were adjusted to the specific test angles by using a Johnson Magnetic Angle Locator (Johnson Level and Tool, Mequon, WI). Two feed samples were collected and weighed at each angle and feeder setting. The feeder settings were 0.91, 1.82, 2.73, 3.64, and 4.55 kg for the Econo and Accu feed drops. Due to the smaller capacity feed reservoir samples were collected at all settings except the 4.55 kg setting for the Ultra feed drop. Samples were weighed on an Ohaus Champ II Bench Scale (Ohaus Balance and Scale, Pine Brook, NJ) which allowed measurement to one hundredth of a kilogram.

Statistical Analysis.

A total of 15 feed drops were blocked based on location on the feed line with one feed drop of each type randomly allotted within each block. There were a total of five blocks on the feed line, with each block consisting of three continuous openings spaced 0.31 m apart. Each block had one feed drop of each type (Econo, Accu, and Ultra) and was randomized for order within the block. Each feed drop was considered as an experimental unit. As part of the experimental protocol, all feed drops were aligned to a specific test angle (90, 75, or 60°) with the drop set to a specific target feed drop setting (0.91 kg, 1.82 kg, etc.). Then, two collections of the accumulated feed amount were weighed. The feed drops were then set to the next targeted amount and the procedure repeated. Finally, the drop was aligned to the next specific test angle with the procedure repeated. This allowed the data to be analyzed as a split-split-plot design with the feed drop as the whole plot and angle and feeder setting as the subplots. The model included the random effect of block and fixed effects of feed drop type, target feed level and angle considered fixed effects. The model included the main effect of drop type, angle setting, and target feed level as well as the interactions of type × angle × feed level and type × feed level. The difference from the target feed level and actual feed collected were used to determine the accuracy of each drop type at all angles and target feed settings. Evaluation of these differences indicated that they were normally distributed. Analysis of variance was performed using the PROC MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Linear regression equations were developed for the mean values of each drop type and angle setting.

RESULTS

There was a feed drop type × angle × feed level interaction ($P < 0.01$) observed for the amount of feed dropped versus the actual feed drop setting (Table 4.2). There also was a type × feed level interaction for the difference in the amount of feed accumulated when the feed drops were moved from a 90 to 60° angle. The Econo feed drop was most affected by angle to the feed line and had a greater ($P < 0.05$) difference in the amount of feed accumulated when the angle changed from 90° to 60° than the Accu or Ultra feed drop. The Econo feed drop had a greater ($P < 0.05$) weight difference from the target weight than the Accu and Ultra feed drop at almost all feeder settings. The Accu feed drop had a greater ($P < 0.05$) weight difference from the target weight than the Ultra feed drop when set at a 60° angle from the feed line at most feeder settings; however, the Accu feed drop was more accurate ($P < 0.05$) at the 90 and 75° angle at all but the lowest (0.91 kg) feeder settings.

There was a type × angle × feed level interaction ($P < 0.01$) observed for the slope and intercept for regression equations developed to predict the amount of feed dropped at each feeder setting. Regression analysis indicated the slope was not equal to one for the Econo feed drop at an angle of 90° ($P < 0.01$), 75° ($P < 0.03$), or 60° ($P < 0.01$; Figure 4.2). The intercept was not equal to zero for the Econo feed drop at an angle of 90° ($P < 0.01$), 75° ($P < 0.01$), or 60° ($P < 0.08$). The regression equation generated to adjust the Econo feed drop for the specific angles are listed as the following: 90°, $y = 1.156x + 0.2438$, $r^2 = 0.99$; 75°, $y = 1.01428x – 0.1387$, $r^2 = 0.99$; 60°, $y = 0.689x – 0.076$, $r^2 = 0.98$.

The slope was equal to one for the Accu feed drop at all three angles ($P > 0.51$; Figure 4.3). The intercept tended to not equal zero for the Accu feed drop at an angle of 90° ($P < 0.09$) and 60° ($P < 0.08$). The regression equation to adjust the Accu feed drop for the specific angles are listed as the following: 90°, $y = 1.0096x + 0.0715$, $r^2 = 0.99$; 75°, $y = 0.9968x + 0.057$, $r^2 = 0.99$; 60°, $y = 0.989x – 0.2493$, $r^2 = 0.99$.

The slope was equal to one for the Ultra feed drop at 90 and 75° ($P > 0.67$), but not equal to one at an angle of 60° ($P < 0.02$). The intercept was equal to zero for the Ultra feed drop at an angle of 90° ($P < 0.01$) and 75° ($P < 0.01$), but was not different ($P > 0.53$) from zero at 60°.The regression equation to adjust the Ultra feed drop for the specific angles are listed as the following: 90°, $y = 1.0088x + 0.2309$, $r^2 = 0.99$; 75°, $y = 1.0054x + 0.1559$, $r^2 = 0.99$; 60°, $y = 0.9509x + 0.0255$, $r^2 = 0.99$.

DISCUSSION

Sows that are housed in gestation stalls are typically fed once or twice daily by volumetric feed drops. Accuracy of the feed drops is important to prevent overfeeding or underfeeding. If sows are overfed they may accumulate backfat levels greater than 21 mm backfat at farrowing and this is associated with reduced feed intake during lactation (Dourmad, 1991; Revell et al., 1998; Young et al., 2004). Conversely, if sows are underfed they may not achieve the desired 17 mm of backfat (Young et al., 2004) and could potentially be at risk of not rebreeding after farrowing. According to Young and Aherne (2005) sow feed costs account for 12% of the producers' total feed costs and the feeding and nutrition of the sow may greatly influence sow lifetime productivity and thus affect profits. This report, to our knowledge, is the first to provide data to determine the accuracy of gestation feed drops.

These three feed drops are designed to be mounted at the 90° angle from the feed line. These data demonstrate that the Accu and Ultra feed drops are more accurate than the Econo feed drop at a 90° angle. As the feed drops became more skewed (decreased angle from feed line), the Econo drop had a greater change in the amount dropped at each setting compared to the other two designs. As the drop is skewed from the 90 to 60° angle setting there is an approximately 50% change in the amount of feed dropped with the Econo feed drop. The same change in angle for the Accu and the Ultra feed drop only resulted in an approximately 10% change.

The difference in accuracy at the different angle settings is potentially related to the way that the different drops attach to the feed line. As shown in Figure 4.1, the Accu and Ultra feed drops are attached to the feed line along the entire top of the drop. Conversely, the Econo feed drop is only attached at the middle of the top at the back of the drop. The Econo and the Ultra feed drop are actually similar in shape and measuring system. Both feed drops are "box" shape and measure the amount of fill by use of a "ribbon" measuring system where the feed enters the drop through a chute and fills until the feed level reaches an adjustable "ribbon". However, the box, and ultimately the feed delivery chute are turned 90° for the Ultra compared with the Econo feed drop. Because of this, when the drop is rotated away from a perpendicular angle from the feed line, the feed flow is affected to a greater extent with the Econo than the Ultra feed drop.

For the Accu feed drop, feed volume is determined by the height setting for the plate within the cylinder. The volume that can enter the cylinder doesn't change greatly as the angle to the feed line changes. One potential concern with this design is that if the plate doesn't remain on a consistent plane with the feed settings on the cylinder, the drop may become more difficult to set. The volume entering the cylinder wouldn't change if the plate was not flat; however, determining the exact setting would be more difficult. A simple and economic solution to this problem would be for the manufactures to print four equally spaced measuring labels on the sides of the cylinder.

However, it appears that the amount of feed that is collected in each drop appears to increase linearly as the feeder settings are increased, regardless of the angle setting (90, 75, or 60°). Thus, regression equations for each type of feed drop to adjust for the variability in the amount of feed that is accumulated can be developed for the angle of the feed drop to the feed line. Unfortunately, this requires feed drops all set at the same angle to the feed line. Alternatively, a separate equation could be developed for each angle. This information highlights the importance of feed drops being maintained at the same angle relative to the feed line within a production facility.

The accuracy of different feed drop may have a large economic impact of gestating gilts and sows due to an over and under consumption of nutrients and the subsequent performance loss. As an example, a 250 kg sow has a maintenance requirement of approximately 2.0 kg if fed a standard gestation diet. If an Econo feed drop was set at 2.73 kg to provide feed to this sow (for desired weight gain), it would then supply the sow with 1.4 and 0.6 kg of feed above maintenance requirements when the feed drop is at an angle of 90 and 75° from the feed line respectively. If the feed drops were set at a 60° angle the sow would receive 0.3 kg of feed less than the amount required for maintenance. If the feed drop remained on the same feed setting for the entire gestation period, the sow could be losing weight (60° angle) or gaining as much as 50 kg (90° angle) depending on the orientation of the feed drop to the feed line. Conversely, if the Accu feed drop was set at 2.73 kg to feed the same sow; she would receive 0.8, 0.7, and 0.4 kg of feed above maintenance when set at angles of 90, 75, and 60°. The amount of weight gain over a gestation period would be more consistent within a range of 15 to 28 kg.

These data indicate that the type of gestation feed drops and their angle relative to the feed line influences the accuracy of the amount of feed dispensed relative to the feeder setting.

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Table 4.1. Composition of diets (as-fed basis)

Item	%
Corn	63.14
Soybean meal (46.5 % CP)	33.26
Monocalcium P (21% P, 18%C)	1.40
Limestone	1.25
Salt	0.35
Trace mineral premix[1]	0.20
Vitamin Premix[2]	0.15
L-Lysine HCL	0.15
L-threonine	0.05
DL-methionine	0.05
Total	100.00
Calculated composition	
ME, kcal/kg	3,287
CP, %	21.00
Total lysine, %	1.29
Total threonine, %	0.85
Total methionine and cystine, %	0.75
Analyzed composition	
CP, %	20.92
Total lysine, %	1.18
Total threonine, %	0.83
Total methionine and cystine, %	0.72

[1]Premix provides potency levels of following nutrients per kg: Copper at 11 g, Iodine at 198 mg, Iron at 110 g, Manganese at 26 g, Selenium at 198 mg, Zinc at 110 g.
[2]Premix provides potency levels of following nutrients per kg: Vitamin A at 4,400,000 IU, Vitamin D at 660,000 IU, Vitamin E at 17,6000 IU, Vitamin K at 1,760 mg, Vitamin B_{12} at 15 mg, Niacin at 19,800 mg, Pantothenic acid at 11,000 mg, Riboflavin at 3,300 mg.

Table 4.2 Difference in weight of feed dropped versus actual feed drop setting[1]

	Feed Drop			
	Econo	Accu	Ultra	SE
0.91 kg[2]				
90°	0.23[a]	0.09[b]	0.14[ab]	0.02
75°	0.05	0.13	0.07	0.02
60°	-0.21	-0.19	-0.10	0.02
Weight difference from 90 to 60°[3]	0.44	0.28	0.24	0.08
1.82 kg[2]				
90°	0.45[a]	0.07[b]	0.35[ab]	0.03
75°	-0.18[a]	-0.02[b]	0.27[c]	0.03
60°	-0.73[a]	-0.38[b]	0.02[c]	0.03
Weight difference from 90 to 60°[3]	1.18[a]	0.46[b]	0.32[b]	0.08
2.73 kg[2]				
90°	0.74[a]	0.11[b]	0.34[c]	0.03
75°	-0.09[a]	-0.02[a]	0.23[b]	0.03
60°	-1.05[a]	-0.29[b]	-0.04[c]	0.03
Weight difference from 90 to 60°[3]	1.78[a]	0.39[b]	0.40[b]	0.08
3.64 kg[2]				
90°	0.61[a]	0.09[b]	0.16[b]	0.04
75°	-0.13[a]	0.04[b]	0.09[b]	0.04
60°	-1.30[a]	-0.25[b]	-0.23[b]	0.04
Weight difference from 90 to 60°[3]	1.90[a]	0.34[b]	0.39[b]	0.08
4.55 kg[2]				
90°	0.63[a]	0.12[b]	---	0.05
75°	0.22[a]	0.09[b]	---	0.05
60°	-1.35[a]	-0.31[b]	---	0.05
Weight difference from 90 to 60°[3]	1.97[a]	0.43[b]	---	0.08

[a-c]Values within a row lacking a common superscript letter are different ($P < 0.05$).
[1]The Ultra feed drop was not measured at 4.55 kg due to limited storage capacity.
[2]Type × angle × feed level interaction ($P < 0.01$).
[3]Type × feed level interaction ($P < 0.01$).

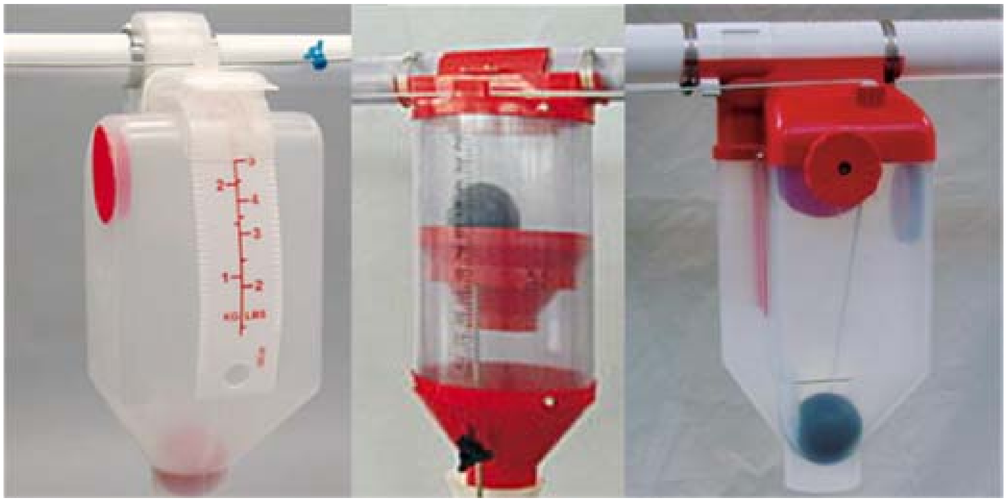

Figure 4.1 Picture of feed drops used in the experiment. Left to right: Econo, Accu, and the Ultra feed drop. Photos courtesy of Automated Production Systems, Assumption, IL (www.automatedproduction.com).

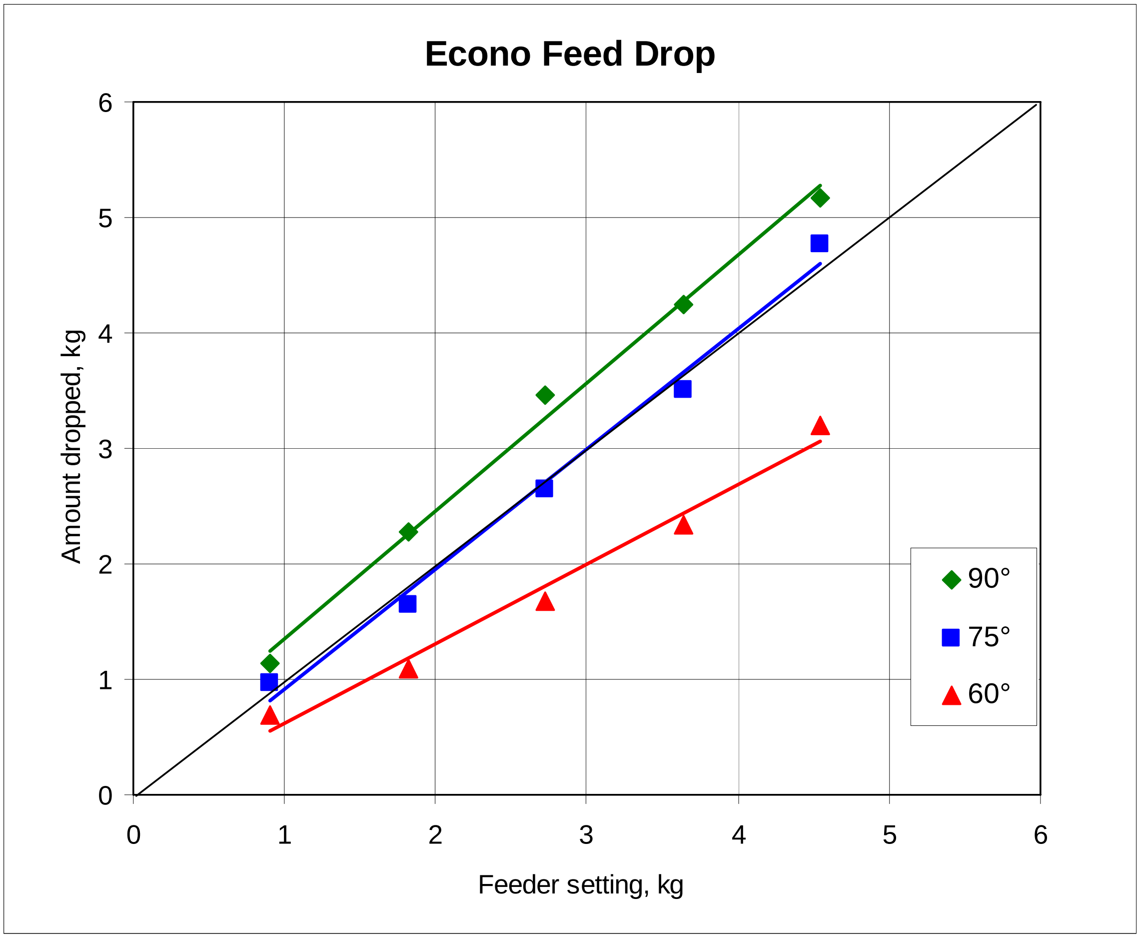

Figure 4.2 Example of the actual amount of feed dispensed for each feeder setting among the respected angles tested for the Econo feed drop. Regression equations for the specific angles are listed as the following: 90°, y = 1.156x + 0.2438, r^2 = 0.99; 75°, y = 1.01428x – 0.1387, r^2 =0.99; 60°, y = 0.689x – 0.076, r^2 = 0.98.

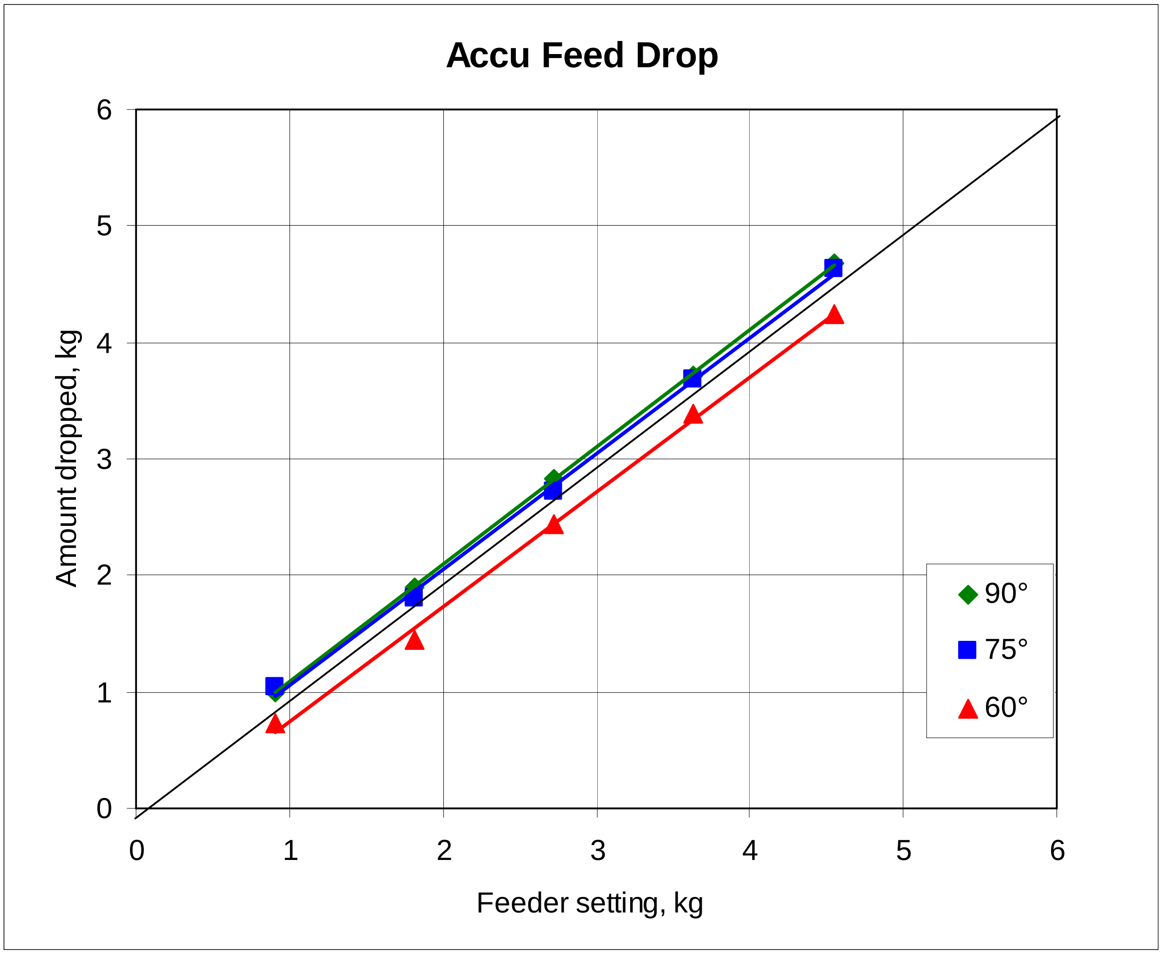

Figure 4.3 Example of the actual amount of feed dispensed for each feeder setting among the respected angles tested for the Accu feed drop. Regression equations for the specific angles are listed as the following: 90°, $y = 1.0096x + 0.0715$, $r^2 = 0.99$; 75°, $y = 0.9968x + 0.057$, $r^2 = 0.99$; 60°, $y = 0.989x - 0.2493$, $r^2 = 0.99$.

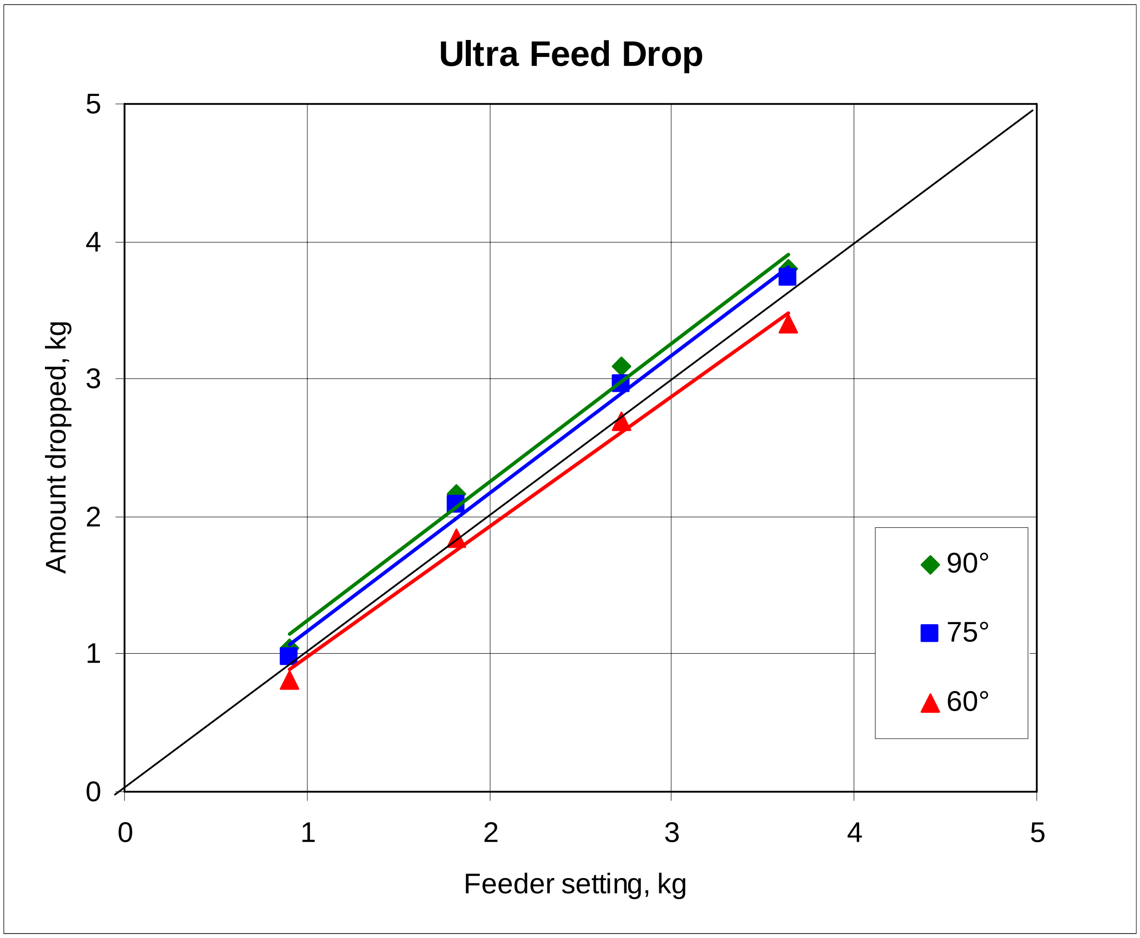

Figure 4.4 Example of the actual amount of feed dispensed for each feeder setting among the respected angles tested for the Ultra feed drop. Regression equations for the specific angles are listed as the following: 90°, $y = 1.0088x + 0.2309$, $r^2 = 0.99$; 75°, $y = 1.0054x + 0.1559$, $r^2 = 0.99$; 60°, $y = 0.9509x + 0.0255$, $r^2 = 0.99$.

CHAPTER 5 - The optimal true ileal digestible lysine and total sulfur amino acid requirement for two genetic lines of nursery pigs between 10 and 20 kg

ABSTRACT: Two experiments were conducted to determine the optimal true ileal digestible (**TID**) Lys and TSAA requirement of two different genetic lines of nursery pigs, and consequently to determine the optimal TID TSAA:lysine (**TSAA:Lys**) ratio. Each experiment was organized as a combination of two simultaneous studies with one set of diets consisting of five TID Lys levels and the second set of diets consisting of five TID TSAA levels. The highest concentration of both Lys and TSAA was combined as one diet and used both the Lys and TSAA studies. In Exp. 1, 360 pigs (avg. BW = 10.3 kg, Genetiporc) were randomly allotted to eight replications with five pigs per pen. Pigs were fed diets containing 0.90, 1.00, 1.10, 1.20, and 1.30% TID Lys or 0.56, 0.62, 0.68, 0.74, and 0.81% TID TSAA. Overall, (d 0 to 21) ADG and G:F increased (linear, $P < 0.01$; quadratic, $P < 0.05$, respectively), while ADFI tended to decrease (linear, $P < 0.07$) with increasing TID Lys. Increasing TID TSAA increased (linear, $P < 0.03$) ADG and G:F. Although the response to increasing TID TSAA was linear, only small improvements in growth performance were observed from 0.68% to 0.81% TID TSAA. The various models used in this trial estimated that the Genetiporc pig required range of TID TSAA:Lys ratio from approximately 64 to 68% for optimal G:F. In Exp. 2, 360 pigs (avg. BW = 10.0 kg, PIC) were fed diets containing 1.05, 1.15, 1.25, 1.35 and 1.45% TID Lys or 0.61, 0.69, 0.76, 0.83 and 0.90% TID TSAA. Overall (d 0 to 21) ADG and G:F increased (quadratic, $P < 0.01$) with increasing TID Lys and TID TSAA. The various models used in this trial estimated that the PIC pig required range of TID TSAA:Lys ratio from approximately 54 to 58% for G:F. Although the two sources of genetics were not compared in the same study, ADG was similar for both genetics sources; however, pigs in Exp. 2 (PIC) consumed less feed per day which resulted in greater feed efficiency than in Exp. 1 (Genetiporc). Pigs in Exp. 1 required less TID Lys to maximize ADG and G:F than the pigs in Exp. 2, but the required TID TSAA was similar. Thus,

the optimal TID TSAA:Lys ratio for PIC pigs was lower than the optimal ratio for Genetiporc pigs.

Keywords: Lysine, TSAA, nursery pigs

INTRODUCTION

The TSAA have been shown to be adequate for growth in conventional corn-soybean meal based diets (Chung and Baker, 1992b). However, in recent years the use of low protein amino acid fortified diets has increased due to increased availability and decreased cost of crystalline amino acids, as well as concerns regarding N excretion in waste. Thus, it is essential to accurately define the ratio of other amino acids to Lys in order to properly utilize crystalline amino acids and lower feed cost. Chung and Baker (1992b) suggested a TSAA requirement of 0.58% of the diet and an ideal ratio to Lys of about 60%. This is in agreement with recent data of Gaines et al. (2005) who also suggests a ratio of approximately 60%. The National Research Council (NRC, 1998) suggests a true ileal digestible (**TID**) TSAA:lysine (**TSAA:Lys**) ratio of 57% for the 10 to 20 kg pig.

Chung and Baker (1992b) indicate the variability in TSAA:Lys ratios reported in other trials may be explained by the use of differing response criteria, weight and genetics of pigs, and the bioavailability and type of diet used in these studies. Furthermore, a frequent limitation of amino acid ratio experiments is failure to determine the actual Lys requirement of the pigs used in the studies (Owen et al., 1995b). Numerous studies calculate a ratio based on the Lys levels used in the experimental diets, while others may estimate Lys requirements from previous studies or National Research Council estimates to extrapolate a ratio.

Results from Kendall et al. (2002) and Gaines et al. (2003) suggest that modern nursery pigs have a higher TID Lys requirement than suggested by the current NRC (1998) estimates.

However, data concerning the TID TSAA needs of the modern nursery pig is limited and has only been conducted with DL-Methionine as the methionine source (Chung and Baker, 1992b; Owen et al., 1995a, b; Matthews et al., 2001). Thus, the objective of these experiments was to concurrently determine the optimal dietary Lys and TSAA requirement in experiments with two different genetic lines, and hence, obtain the appropriate TID TSAA:Lys ratio for maximum growth performance in the modern nursery pig.

MATERIALS AND METHODS

General.

The experimental protocols used in these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee.

A total of 360 Genetiporc pigs (St. Bernad, Quebec, Canada) and 360 PIC pigs (Franklin, KY) were used in two separate experiments. Pigs were housed at the Kansas State University Segregated Early-Weaning facility. This facility was environmentally regulated to maintain animal comfort and the initial temperature (34ºC) was reduced by 1.5ºC each week. All pens (1.8 m^2) contained woven wire flooring and held five pigs. Pigs were given ad libitum access to feed and water through a dry feeder and one nipple water per pen. At the initiation of the trial, pigs were allotted by initial BW and randomly assigned to dietary treatments with eight replicate pens per treatment in each of the respective experiments. The pigs and feeders were weighed on d 7, 14, and 21 of the trial to determine ADG, ADFI, and G:F.

Blood samples were obtained by venipuncture on d 12 from two randomly selected pigs in each pen following a 3-h period of feed deprivation and analyzed for plasma urea N (PUN) and amino acid concentration. The samples were centrifuged at 2,500 × g for 25 min within 1 h of collection. Plasma was collected and stored at -20ºC until it was analyzed. Samples were analyzed for urea N concentration with an autoanalyzer (Alpkem, Clackamas, OR). Amino acid analysis was done by ion exchange chromatography.

Diets.

All experimental diets were corn-soybean meal-based and were fed in a meal form throughout the 21-d experiment (Table 5.1). Each experiment was organized as a combination of two separate trials with one set of diets consisting of five TID Lys concentrations (Exp. 1, 0.90, 1.00, 1.10, 1.20, and 1.30%; Exp. 2, 1.05, 1.15, 1.25, 1.35, and 1.45%). Other crystalline amino acids were added to meet minimum ratios and to ensure Lys was first limiting. The second sets of five diets were formulated to the highest TID Lys content (Exp. 1, 1.3%; Exp. 2, 1.45%) with increasing TID TSAA (Exp. 1, 0.56, 0.62, 0.68, 0.74, and 0.81%; Exp. 2, 0.61, 0.69, 0.76, 0.83, and 0.90%). Diets were formulated in Exp. 1 and Exp. 2 to contain similar TID TSAA:Lys ratios of 42, 47, 52, 57, and 62%. The highest level of both Lys and TSAA (Exp. 1, 1.3% and 0.81%; Exp. 2, 1.45% and 0.90%, respectively) diet was combined as one treatment and used in both the Lys and TSAA titrations to give a total of 10 treatments. The diets containing the high and low inclusion level of TID TSAA and Lys were blended to form all intermediate diets. Alimet® (an 88% aqueous solution of DL-2-hydroxy-4-(methylthio) butanoic acid; **DL-HMB**) replaced cornstarch to provide the experimental TSAA concentrations. It was assumed that the Alimet® contained 88% methionine; therefore, a conversion factor was used to ensure that the level added was on a molar equivalent basis compared to DL-methionine. Earlier it has been reported that the efficacy of Alimet and DL-methionine, when both are formulated on the same molar equivalency, is similar for the young early weaned pig (Chung and Baker 1992a, d; Knight et al., 1998; Jansman and de Jong, 1999; Gaines et al., 2005; Yi et al., 2005). Dietary AA and DL-HMB were analyzed at the feed analytical laboratory of Novus International, Inc. Results of diet analysis confirmed that analyzed to theoretical supplementation levels were within the standard laboratory variation.

Experiment 1.

A total of 360 pigs (initially 10.3 kg) were used in a 21-d growth assay to determine the appropriate total sulfur amino acid to Lys ratio for Genetiporc nursery pigs weighing 10 to 20 kg. Pigs were blocked by weight and randomly allotted to 10 experimental treatments.

The diets used in the Lys titration study consisted of five increasing TID Lys levels of 0.99, 1.07, 1.15, 1.22, and 1.30%. The diets were formulated with additions of other crystalline amino acids to maintain a minimum ratio and to make certain Lys was first limiting. The second set of five diets consisting of five increasing TID TSAA levels (0.56, 0.62, 0.68, 0.74, and 0.81%) was formulated to contain 1.30% TID Lys. The intermediate diets used in this trial were formed by blending the diets containing 0.90% TID Lys with 0.61% TID TSAA, 1.30% TID Lys with 0.56% TID TSAA, and 1.30% TID Lys with 0.81% TID TSAA.

Experiment 2.

Three hundred sixty barrows and gilts (PIC; initially 10.0 kg) were blocked by weight and randomly allotted based on BW to one of 10 dietary treatments. There were eight replicates per treatment. All pigs were fed the experimental diets in a 21-d growth trial. The first set of diets consisted of five increasing TID Lys levels (1.05, 1.15, 1.25, 1.35, and 1.45%); other crystalline amino acids were added to meet minimum ratios and to ensure Lys was first limiting. The second set of diets was formulated to 1.45% TID Lys with increasing TID TSAA levels (0.61, 0.69, 0.76, 0.83, and 0.90%). The highest level of both Lys and TSAA (1.45% and 0.90%, respectively) was combined as one diet and used in both the Lys and TSAA titrations to give a total of 10 treatments. The diets containing 1.05% TID Lys with 0.61% TID TSAA, 1.45% TID

Lys with 0.61% TID TSAA, and 1.45% TID Lys with 0.90% TID TSAA were blended to form all intermediate diets.

Statistical Analysis.

Data in Exp. 1 and Exp. 2 were analyzed as a randomized complete block design with pen as the experimental unit. Pens were blocked on the basis of initial weight. The model included the fixed effect of treatment and block was the random effect. Analysis of variance was performed using the MIXED procedure of SAS (SAS Inst., Inc., Cary, NC), and linear and quadratic polynomials (Steel et al., 1997) were evaluated. Three different methods were used to estimate the optimal TID AA, and thus the TID TSAA:Lys ratio for each experiment. The first estimate was obtained using a one-slope broken-line regression model using the NLIN procedure of SAS (Robbins et al., 2006). The second estimate was determined by establishing the first point where the quadratic curve intersected the broken-line (above the breakpoint) as described by Parr et al. (2003). The third estimate was based on the 95% quadratic maximum calculated from the quadratic model (Gaines et al., 2005).

RESULTS

Experiment 1.

From d 0 to 21, ADG increased (linear, $P < 0.01$) and ADFI tended to decrease (linear, $P < 0.07$) with increasing TID Lys (Table 5.3). Increasing TID Lys increased G:F (quadratic $P < 0.05$) with the greatest improvement in G:F observed as TID Lys increased from 0.90 to 1.10% with smaller improvements from 1.10 to 1.30%. Increasing TID TSAA increased (linear, $P < 0.03$) ADG and improved (linear, $P < 0.01$) G:F (Table 5.4). Although there was a linear response to ADG and G:F; the greatest response was seen as TID TSAA increased from 0.56 to

0.68% with small improvements observed as TID TSAA increased from 0.68 to 0.81%. Analysis of plasma on d 12 showed a decrease (linear, $P < 0.01$; Tables 5.7 and 5.8) in plasma urea N as both TID Lys and TSAA were increased in the experimental diets. Plasma Lys increased (linear, $P < 0.01$) whereas plasma histidine, phenylalanine, tryptophan, and valine decreased (linear, $P < 0.02$) when TID Lys levels were increased. Analysis of essential amino acids shows that increasing TID TSAA had a tendancy to increase (linear, $P < 0.07$) methionine while histidine, isoleucine, Lys, threonine, and valine had a tendency to decrease (linear, $P < 0.10$). The one-slope broken-line model, the first x-intercept value of the broken-line and quadratic model, and 95% of quadratic maximum provide estimates of the optimal TID Lys requirements of 1.03, 1.17, and 1.24% for ADG and 1.06, 1.11, and 1.19% for G:F. The same models provide estimates for the optimal TID TSAA requirements of 0.68, 0.73, 0.74% for ADG and 0.70, 0.75, 0.76% for G:F. Thus, estimated TID TSAA:Lys ratios were 66, 62, and 60% for ADG using the three models and 66, 68, and 64% for G:F. Based on plasma concentrations, the optimal TID TSAA:Lys requirements for PUN and Plasma AA was 60% using all three models.

Experiment 2.

From d 0 to 21, ADG increased (quadratic, $P < 0.01$; Table 5.5) with increasing TID Lys; however, ADFI was not affected ($P > 0.28$) by TID Lys levels. Also, increasing TID Lys increased G:F (quadratic, $P < 0.01$). The largest improvement in ADG and feed efficiency occurred as TID Lys increased from 1.05 to 1.25 and 1.35%, respectively; however, there was little improvement in growth as TID Lys increased from 1.25 and 1.35 to 1.45%. Increasing TID TSAA increased (quadratic, $P < 0.01$; Table 5.6) ADG and G:F; however, ADG and feed efficiency was maximized at a TID TSAA level of 0.76 and 0.83% respectively. Average daily feed intake was not affected ($P > 0.44$) by increasing TID TSAA. Plasma urea N decreased (linear, $P < 0.01$; Tables 5.9 and 5.10) on d 12 as TID Lys and TID TSAA increased. Analysis of essential amino acids show that increasing TID Lys increased (linear, $P < 0.07$; $P < 0.01$) Lys and methionine while phenylalanine and valine were decreased (linear, $P < 0.03$). Plasma methionine increased (quadratic, $P < 0.04$) whereas plasma Lys, valine, and threonine decreased (linear, $P < 0.01$; linear, $P < 0.01$; quadratic, $P < 0.02$) when TID TSAA levels were increased. The one-slope broken-line model, the first x-intercept value of the broken-line and quadratic model, and 95% of quadratic maximum provided estimates of the optimal TID Lys requirements of 1.17, 1.25, and 1.28% for ADG and 1.22, 1.29, and 1.34% for G:F. Estimates for the optimal TID TSAA requirements using the three models were 0.75, 0.74, 0.78% for ADG and 0.71, 0.70, 0.78% for G:F. Thus, suggested TID TSAA:Lys ratios were 64, 59, and 61% for ADG and 58, 54, 58% for G:F. Due to the inability of the one-slope broken-line model to identify an adequate breakpoint, only the 95% of quadratic maximum was used for the blood analysis. It provided optimal TID TSAA:Lys requirements of 62% for PUN and 59% for Plasma AA.

DISCUSSION

Chung and Baker (1992b) proposed that there are several factors that may contribute to the differences in TSAA requirement estimates of the growing pig such as: 1) use of different response criteria, 2) genetics and weight, 3) variation in diets used, 4) use of tabulated rather than analytical values of the amino acid, and 5) analytical variation due to difficulties in measuring certain amino acids. These factors may have a profound effects on the ideal amino acid ratio (to Lys) if they were to cause an over or under estimation of the actual requirement for TSAA. Several researcher have attempted to determine a requirement using either only empirical estimates (Chung and Baker, 1992b), inflection point analysis (Owen et al., 1995a, b), two slope broken-line regression analysis (Matthews et al., 2001; Yi et al., 2006), and economic comparisons (Gaines et al., 2005). Therefore, TSAA requirement may differ depending on maximal response in these data sets. For example, a linear broken-line regression may produce a visually satisfactory fit and be sufficient for certain data sets (Robbins et al., 2006). However, in other data sets the response may be curvilinear and the single-breakpoint model will underestimate the requirement. Additionally, earlier studies typically tended to estimate amino acid ratios from the actual Lys levels used in their experimental diets or to extrapolate an estimated Lys requirement from a predetermined source such as past experiments or NRC (1998) values. According to Owen et al. (1995b), these procedures to estimate an appropriate ideal amino acid ratio are flawed based on their willingness to accept Lys levels that may not be accurate for specific genetics or production systems. Researchers may not correctly estimate ideal amino acid ratios if there is a wide variation between the Lys levels used in a particular trial and the actual Lys requirement of the pig. Therefore, in a factorial study the Lys levels used may not fully meet the requirement of the growing pig. Furthermore, the optimal amino acid estimate derived in a titration study would be related to the Lys level used that experiment. By definition, dividing a specific amino acid requirement with an extrapolated Lys requirement of another trial or NRC values would incorrectly estimate an amino acid ratio (Owen et al., 1995b). In addition, Lys and TSAA requirements may be affected by the different genetics and weight of the pig. This may be the result of difference in protein deposition and feed intake of modern genetics. Thus, the modern pig may require an increasing amount of amino acids to maximize growth and performance. Also, results may vary depending on the diets used each study. Recently, there has been debate over the biological efficacy of DL-HMB (Yi et al., 2006), which was used in this study. Previous dose response comparisons (Yi et al., 2006; Gaines et al., 2005; Jansmand and de Jong, 1999; Knight et al., 1998) have concluded the DL-HMB and DL-Methionine supplied equimolar amounts for the nursery pig, while other data is in contrast of these results (Roth and Kirschgessner, 1986; Locatelli and Hall, 2005). Finally, the inconsistent reports regarding the TSAA requirement of pigs may be due to the difference in cysteine (**Cys**) replacement value. Chung and Baker (1992c) reported that Cys can furnish 50% of the total TSAA requirement. However, Curtin et al. (1952) and Baker et al. (1969) estimated the 53 and 56% of TSAA could be satisfied by Cys.

In this study, the one-slope broken-line analysis, x-intercept value of the broken-line and the quadratic curve, and the 95% quadratic maximum indicated a TID Lys requirements for Genetiporc pigs of 1.03, 1.17, and 1.24 for ADG and 1.06, 1.11, and 1.19% for G:F. The TID TSAA requirement for ADG was 0.68, 0.73, and 0.74% while the requirement for G:F was 0.70, 0.75, and 0.76%, respectively. Therefore, the TID TSAA:Lys ratio Genetiporc pigs is calculated to be 66, 62, and 60% for maximal ADG and 66, 68, and 64% for maximal G:F. The TID Lys requirement for PIC pigs was determined to be 1.17, 1.25, and 1.28% for ADG and 1.22, 1.29, 1.34% for G:F. The TID TSAA requirement for maximal ADG was 0.75, 0.74, and 0.78% while the requirement for maximal G:F was 0.71, 0.70, and 0.78%, respectively. Thus, the TID TSAA:Lys ratio for PIC pigs is calculated to 64, 59, and 61% for maximal ADG and 58, 54, and 58% for maximal G:F. The different estimated TID TSAA:Lys ratio between Exp. 1 and 2 may be explained by the difference in feed efficiency of the genetics used in this experiment. While the estimated optimal TID TSAA requirement for G:F and ADG was similar for the Genetiporc and PIC pigs, the estimated TID lysine requirement was higher for the PIC genetics. Therefore, the PIC genetics in Exp. 2 had a lower TID TSAA:Lys ratio than the Genetiporc pigs in Exp. 1.

The NRC (1998) estimates the TID Lys and TID TSAA requirements for the 10- to 20 kg pig to 1.01 and 0.58%, respectively. Thus, representing a TID TSAA:Lys ratio of 57.4%.

Chung and Baker (1992b, d) proposed a true digestible methionine requirement of approximately 0.29% for the 10 to 20 kg pig. This value corresponds to a TSAA:Lys ratio of 58% when cysteine is assumed to provide 50% of the TSAA requirement. However, modern lean-genotype pigs have increased protein deposition rates, thus a higher requirement for amino acids then suggested by current NRC (1998) estimates (Kendall et al., 2002; Gaines et al., 2003). Recently PIC (2003) recommended a higher TID Lys and TID TSAA requirement (1.42 and 0.89%) for the 7- to 11-kg pigs and (1.32 and 0.83%) the 11- to 23-kg pigs, respectively. This recommendation is in agreement with the estimated TID Lys requirement of 1.40 and 1.30% for maximal growth performance of 10- to 20-kg and 11- to 26-kg PIC pigs (Lenehan et al. 2003; Yi et al. 2006). Previously, Gaines et al. (2004) estimated the TID TSAA requirement for the 13- to 25-kg pig is 0.73 to 0.77% for maximal ADG and 0.80 to 0.83% for optimal feed efficiency. Furthermore, Yi et al. (2006) suggested that the TID TSAA requirement to be 0.77% and 0.83% for maximal ADG and G:F for the 10-20 kg pig of PIC genotype. Our research found a similar requirement for PIC and Genetiporc pigs for ADG and G:F of 0.70 to 0.78% TID TSAA.

Even though the modern pig may require an increasing amount of amino acids to optimize growth and performance, Gaines et al. (2005) reported that it is unlikely that the optimal TSAA:Lys ratio has changed substantially. The current research data suggested a TID TSAA:Lys ratio of 66, 62 and 60% to maximize ADG and 66, 68, and 64% to optimize G:F for the 10- to 20-kg Genetiporc pigs used in Exp. 1. These estimates are higher than the values for the 13- to 26-kg Genetiporc pigs reported by Gaines et al. (2005). In that study, Gaines et al. (2005) utilized three similar methods (two-slope broken line, two slope broken line × quadratic maximum intercept, and a 95% quadratic maximum) to determine an optimal TSAA:Lys ratio of 59.7, 60.2, 57.0% for ADG and 61.6, 62.5, 61.0% for G:F, respectively. In Exp. 2, analysis of the response surface estimated that the PIC pigs used in this trial would require an TID TSAA:Lys ratio of 64, 59, and 61% to maximize ADG and 58, 54, and 58% optimize G:F, whereas the NRC (1998) value for pigs of this weight range is approximately 58%. Additionally, Gaines et al. (2005) reported that Triumph-4 × Camborough 22 pigs ranging from 8- to 19 kg and 12- to 26 kg required a TID TSAA:Lys ratio approximately 59 to 61% to optimize ADG and G:F, respectively. Yi et al. (2006) reported a TID TSAA:Lys ratio of 59 to 63% for maximal ADG and G:F in similar genetics. Recently, Peak (2005) conducted a literature review in which he suggested the TID TSAA:Lys ratio to be 60 to 62% for nursery and growing pigs of modern genotypes.

Coma et al. (1995) suggested that plasma urea N (PUN) can accurately estimate the dietary amino acid requirement the pig in a relative short amount of time. In Exp. 1, PUN concentrations on d 12 decreased as TID Lys and TID TSAA increased. Even though PUN decreased linearly as TID TSAA increased, little improvement was noticed from TID TSAA levels of 0.68 to 0.81%. In Exp. 2, blood analysis shows a decrease in plasma urea N as both TID Lys and TSAA were increased in the experimental diets. Additionally, PUN was numerically lowest at a TID TSAA level of 0.83%. In a typical amino acid dose titration study, PUN and amino acid concentrations should decrease as the limiting amino acid is increased and approaches the pig's requirement (Coma et al., 1995). This suggests that when dietary TSAA was insufficient, protein deposition was limited, resulting in increased levels of urea in plasma. However, as dietary methionine increased and approached the pig's requirement, N was redirected from urea to protein synthesis. An evaluation of the plasma free amino acid levels may prove to be a better assessment of the animal's amino acid status then nitrogen retention (Mitchell et al., 1968). In Exp. 1, methionine increased linearly as the TID TSAA was increased in the diet; however, methionine was numerically the highest at 0.74% TID TSAA. In Exp. 2, there was a quadratic increase in methionine with the highest numerical TID TSAA level at 0.83%. Using the various models in this study, the TID TSAA:Lys ratio was estimated to be approximately 60% for both genetics for plasma amino acids.

In conclusion there are many factors that may determine the variation in the TSAA:Lys ratios that are reported. The two sources of genetics were not compared directly; however, the level of ADG was similar for both genetic sources. Pigs in Exp. 2 (PIC) consumed less feed per day which resulted in greater feed efficiency than in Exp. 1 (Genetiporc). While the requirement for TID TSAA was similar for both genetics, pigs in Exp. 2 (PIC) required higher levels of TID Lys. Therefore, the TID TSAA:Lys ratio was lower for PIC pigs at approximately 57 and 61% for G:F and ADG than the optimal ratio for Genetiporc pigs of approximately 66 and 63% for G:F and ADG, respectively.

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Table 5.1 Composition of experimental diets (as-fed basis)[12]

	Exp. 1			Exp. 2		
	TID lysine/TSAA, %			TID lysine/TSAA, %		
Item, %	0.90/0.61	1.30/0.81	1.30/0.56	1.05/0.65	1.45/0.90	1.45/0.61
Corn	65.90	65.90	65.90	60.02	60.00	60.00
Soybean meal (46.5% CP)	27.65	27.65	27.65	33.42	33.43	33.44
Soybean oil	1.50	1.50	1.50	1.50	1.50	1.50
Monocalcium P (21 % P, 18 % Ca)	1.55	1.55	1.55	1.55	1.55	1.55
Limestone	0.95	0.95	0.95	0.95	0.95	0.95
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[4]	0.15	0.15	0.15	0.15	0.15	0.15
Antibiotic	0.50	0.50	0.50	0.50	0.50	0.50
L-isoleucine	---	0.02	0.02	0.02	0.02	0.02
L-valine	---	0.08	0.08	0.03	0.08	0.08
L-tryptophan	---	0.03	0.03	---	0.03	0.03
L-threonine	---	0.25	0.25	0.02	0.27	0.27
Alimet®[5]	---	0.29	---	0.05	0.33	---
L-Lysine HCL	0.02	0.53	0.53	0.02	0.53	0.53
Corn starch	1.18	0.01	0.30	1.17	0.06	0.38
Total	100.00	100.00	100.00	100.00	100.00	100.00

[1]The diet that contained 0.90% true ileal digestible (TID) Lys and 0.61% TID TSAA was blended with the diet that contained 1.30% TID Lys and 0.81% TID TSAA to achieve the intermediate diets with TID Lys levels of 1.07, 1.15, and 1.22%. The diet that contained 1.30% TID Lys and 0.56% TID TSAA was blended with the diet that contained 1.30% TID Lys and 0.81% TID TSAA to achieve the intermediate diets with TID TSAA levels of 0.62, 0.68, and 0.74%.
[2]The diet that contained 1.05% TID Lys and 0.65% TID TSAA was blended with the diet that contained 1.45% TID Lys and 0.90% TID TSAA to achieve the intermediate diets with TID Lys levels of 1.15, 1.25, and 1.35%. The diet that contained 1.45% TID Lys and 0.61% TID TSAA was blended with the diet that contained 1.45% TID Lys and 0.90% TID TSAA to achieve the intermediate diets with TID TSAA levels of 0.69, 0.76, and 0.83%.
[3]Provided (per kilogram of complete diet): 10,012 IU of vitamin A; 1,502 IU of vitamin D_3; 40 IU of vitamin E; 4.0 mg of vitamin K; 45.05 mg of niacin; 25.03 mg of pantothenic acid; 7.5 mg of riboflavin; and 0.035 mg of B_{12}.
[4]Provided (per kilogram of complete diet): 36.04 mg of Mn; 150.18 mg of Fe; 150.18 mg of Zn; 15.02 mg of Cu; 0.27 mg of I; and 0.27 mg of Se and provided 11.36 mg of carbadox per kg of complete diet.
[5]Alimet feed supplement is a methionine hydroxyl analog [88% aqueous solution of 2-hydroxy-4-(methylthio)butanoic acid (HMTBA)] supplied by Novus International, Inc., St. Louis, MO

Table 5.2 Analysis of experimental diets (as-fed basis)

	Exp. 1			Exp. 2		
	TID lysine/TSAA, %			TID lysine/TSAA, %		
Calculated nutrient profile	0.90/0.61	1.30/0.81	1.30/0.56	1.05/0.65	1.45/0.90	1.45/0.61
ME, Mcal/kg	3,349	3,349	3,345	3,346	3,348	3,344
CP, %	18.5	18.5	18.5	20.6	20.6	20.6
Total Lys, %	1.02	1.42	1.42	1.18	1.58	1.58
Total Met, %	0.30	0.55	0.30	0.37	0.61	0.33
Total Cys, %	0.33	0.33	0.33	0.36	0.36	0.36
TSAA, %	0.63	0.88	0.63	0.73	0.97	0.69
True ileal digestible Lys, %	0.90	1.30	1.30	1.05	1.45	1.45
True ileal digestible TSAA, %	0.56	0.81	0.56	0.65	0.89	0.61
True ileal digestible Met, %	0.27	0.52	0.27	0.34	0.58	0.30
True ileal digestible Cys, %	0.29	0.29	0.29	0.31	0.31	0.31
Ca, %	0.76	0.76	0.76	0.78	0.78	0.78
Available P, %	0.40	0.40	0.40	0.40	0.40	0.40
Analyzed AA concentrations						
Total Lys, %	1.01	1.47	1.50	1.18	1.54	1.58
Total Met, %	0.32	0.31	0.34	0.35	0.35	0.34
Total Cys, %	0.36	0.36	0.36	0.38	0.38	0.38
TSAA, %[1,2]	0.68	0.67	0.70	0.73	0.73	0.72

[1]In Exp. 1, the diets were supplemented with 0.0, 0.29, and 0.0% Alimet®. Analyzed supplemental DL-HMB levels were 0.0, 0.30, and 0.0%.

[2]In Exp. 2, the diets were supplemented with 0.05, 0.33, and 0.00% Alimet®. Analyzed supplemental DL-HMB levels were 0.05, 0.32, and 0.00%.

Table 5.3 Effect of increasing true ileal digestible (TID) lysine in 10 to 20 kg nursery pig (Exp. 1)[1]

	True ileal digestible lysine, %						*P*-value (*P* <)	
Item	0.90	1.00	1.10	1.20	1.30	SE	Linear	Quadratic
Day 0 to 21								
ADG, g	494	524	535	520	549	17.31	0.01	0.51
ADFI, g	901	887	872	842	865	36.73	0.07	0.34
G:F	0.55	0.60	0.62	0.62	0.64	0.01	0.01	0.05

[1]Mean value of eight replications with five pigs (initially 10.3 kg, Genetiporc) per pen.

Table 5.4 Effect of increasing true ileal digestible (TID) TSAA in 10 to 20 kg nursery pig (Exp. 1)[1]

	True ileal digestible TSAA, %						*P*-value (*P* <)	
Item	0.56	0.62	0.68	0.74	0.81	SE	Linear	Quadratic
Day 0 to 21								
ADG, g	514	528	546	540	549	17.31	0.03	0.41
ADFI, g	879	868	881	867	865	36.73	0.66	0.88
G:F	0.59	0.61	0.62	0.63	0.64	0.01	0.01	0.34

[1]Mean value of eight replications with five pigs (initially 10.3 kg, Genetiporc) per pen.

Table 5.5 Effect of increasing true ileal digestible (TID) lysine in 10 to 20 kg nursery pig (Exp. 2)[1]

	True ileal digestible lysine, %						*P*-value (*P* <)	
Item	1.05	1.15	1.25	1.35	1.45	SE	Linear	Quadratic
Day 0 to 21								
ADG, g	484	535	543	541	550	26.66	0.01	0.01
ADFI, g	763	794	778	758	768	16.47	0.45	0.28
G:F	0.64	0.69	0.71	0.72	0.73	0.01	0.01	0.01

[1]Mean value of eight replications with 5 pigs (initially 10.0 kg, PIC) per pen.

Table 5.6 Effect of increasing true ileal digestible (TID) TSAA in 10 to 20 kg nursery pig (Exp. 2)[1]

	True ileal digestible TSAA, %						P-value (P <)	
Item	0.61	0.69	0.76	0.83	0.90	SE	Linear	Quadratic
Day 0 to 21								
ADG, g	510	537	563	558	550	26.66	0.01	0.01
ADFI, g	762	760	782	767	768	16.47	0.59	0.44
G:F	0.68	0.72	0.73	0.74	0.73	0.01	0.01	0.01

[1]Mean value of eight replications with 5 pigs (initially 10.0 kg, PIC) per pen.

Table 5.7 Effect of increasing true ileal digestible (TID) lysine on concentrations of essential amino acids in plasma (*μM*) in 10 to 20 kg Genetiporc nursery pig (Exp. 1)

	TID lysine, %						*P*-value (*P* <)	
Amino acid[1]	0.90	1.00	1.10	1.20	1.30	SE	Linear	Quadratic
Plasma urea N, mg/dL	4.32	2.79	3.04	2.23	1.88	0.35	0.01	0.29
Histidine	91	78	73	64	52	8.2	0.01	0.91
Isoleucine	96	90	86	82	85	6.7	0.18	0.49
Leucine	179	188	178	164	175	12.8	0.43	0.99
Lysine	77	82	136	161	177	22.4	0.01	0.94
Methionine	29	31	33	32	29	2.3	0.99	0.11
Phenylalanine	83	74	75	64	65	5.0	0.01	0.76
Threonine	263	240	230	242	278	30.3	0.73	0.23
Tryptophan	45	49	39	34	38	3.5	0.02	0.62
Valine	204	188	177	149	165	14.3	0.02	0.41

[1]Mean value of eight replications with two randomly sampled pigs per pen.

Table 5.8 Effect of increasing true ileal digestible (TID) TSAA on concentrations of essential amino acids in plasma (*μM*) in 10 to 20 kg Genetiporc nursery pig (Exp. 1)

	TID TSAA, %						*P*-value (*P* <)	
Amino acid[1]	0.56	0.62	0.68	0.74	0.81	SE	Linear	Quadratic
Plasma urea N, mg/dL	3.31	3.07	1.91	2.64	1.88	0.35	0.01	0.49
Histidine	71	63	49	50	52	8.2	0.07	0.28
Isoleucine	97	101	90	85	85	6.7	0.08	0.95
Leucine	188	191	177	161	175	12.8	0.18	0.69
Lysine	243	226	191	190	177	22.4	0.03	0.64
Methionine	24	26	27	30	29	2.3	0.07	0.52
Phenylalanine	74	71	65	66	65	5.0	0.15	0.58
Threonine	414	404	362	342	278	30.3	0.01	0.46
Tryptophan	45	40	35	39	38	3.5	0.17	0.19
Valine	212	208	176	166	165	14.3	0.01	0.64

[1]Mean value of eight replications with two randomly sampled pigs per pen.

Table 5.9 Effect of increasing true ileal digestible (TID) lysine on concentrations of essential amino acids in plasma (*µM*) in 10 to 20 kg PIC nursery pig (Exp. 2)

	TID TSAA, %						*P*-value (*P* <)	
Amino acid[1]	1.05	1.15	1.25	1.35	1.45	SE	Linear	Quadratic
Plasma urea N, mg/dL	4.92	4.20	3.66	3.33	3.29	0.31	0.01	0.15
Histidine	91	104	97	71	72	15.31	0.16	0.48
Isoleucine	123	121	142	117	120	8.35	0.67	0.26
Leucine	210	207	244	194	208	10.94	0.60	0.21
Lysine	129	120	139	155	171	20.44	0.07	0.55
Methionine	43	52	59	59	60	4.30	0.01	0.19
Phenylalanine	116	111	109	105	97	5.94	0.03	0.78
Threonine	270	341	361	263	331	40.54	0.74	0.42
Tryptophan	42	49	52	43	46	4.48	0.88	0.22
Valine	286	280	292	241	241	13.58	0.01	0.32

[1]Mean value of eight replications with two randomly sampled pigs per pen.

Table 5.10 Effect of increasing true ileal digestible (TID) TSAA on concentrations of essential amino acids in plasma (*µM*) in 10 to 20 kg PIC nursery pig (Exp. 2)

	TID TSAA, %						*P*-value (*P* <)	
Amino acid[1]	0.61	0.69	0.76	0.83	0.90	SE	Linear	Quadratic
Plasma urea N, mg/dL	4.07	4.15	3.15	2.95	3.29	0.31	0.01	0.22
Histidine	115	72	77	79	73	15.31	0.12	0.23
Isoleucine	130	124	119	130	120	8.35	0.59	0.82
Leucine	217	218	209	234	208	10.94	0.98	0.60
Lysine	264	254	166	188	171	20.44	0.01	0.22
Methionine	33	46	57	62	60	4.30	0.01	0.04
Phenylalanine	105	101	98	108	97	5.94	0.62	0.99
Threonine	580	464	331	321	301	40.54	0.01	0.02
Tryptophan	50	48	46	47	46	4.48	0.52	0.87
Valine	312	286	262	275	241	13.58	0.01	0.68

[1]Mean value of eight replications with two randomly sampled pigs per pen.

CHAPTER 6 - Determining the optimal Lysine:Calorie Ratio for Different Genotypes on Growth Performance of 10 to 20 Kilogram Nursery Pigs

ABSTRACT: A total of four experiments using 1,411 pigs were conducted to determine the optimal true ileal digestible (**TID**) Lys:calorie **(Lys:Cal)** ratio. Experiment 1 (360 pigs, avg BW = 10.2 kg, Genetiporc) and 2 (351 pigs; avg BW = 9.3 kg; PIC), were both organized as a combination of two simultaneous experiments with one set of diets consisting of five treatments with increasing TID Lys (Exp. 1, 0.99, 1.07, 1.14, 1.22, and 1.30%; Exp. 2, 1.11, 1.19, 1.26, 1.34, and 1.42%) and the second set of diets consisting of five treatments with increasing energy density (Exp. 1, 2,952, 3,093, 3,236, 3,377, and 3,520 kcal of ME/kg; Exp. 2, 2,956, 3,103, 3,251, 3,399, and 3,547 kcal of ME/kg). Increasing dietary TID Lys increased (linear, $P < 0.01$) ADG and G:F, while increasing dietary ME had no effect on ADG but increased (quadratic, $P < 0.05$) G:F. The optimal Lys:Cal ratio was approximately 3.7 g lysine/Mcal ME. Because the ADG response was linear with increasing TID Lys, Exp. 2 was conducted with higher TID Lys levels. In Exp. 2, increasing dietary TID Lys increased (linear, $P < 0.01$) ADG and G:F. Increasing dietary ME increased (linear, P < 0.01) G:F. The optimal Lys:Cal ratio was approximately 4.1 g lysine/Mcal ME. In Exp. 3 (350 pigs; avg BW = 9.4 kg; Genetiporc) and 4 (350 pigs; avg BW = 7.5 kg; PIC), the optimal Lys:Cal ratios in Exp. 1 and 2 were validated by titrating lysine at two different energy levels. In Exp. 3 and 4, pigs were fed diets with either 2.95 or 3.29 Mcal ME/kg with TID Lys:Cal ratios of 3.1 to 4.1 g/Mcal ME (Exp. 3) and 3.5 to 4.5 g/Mcal ME (Exp. 4). In Exp. 3, there was an ME × Lys:Cal ratio interaction ($P < 0.03$) for ADG. The greatest ADG was achieved for pigs fed a Lys:Cal ratio of 3.60 for pigs fed the low ME diets and a ratio of 3.36 for pigs fed the high ME diets. Feed efficiency increased (quadratic, $P < 0.01$) as Lys:Cal ratio increased with the best G:F observed at 3.35 g/Mcal ME. In Exp. 4, there was a tendency for ME × Lys:Cal ratio interaction ($P < 0.08$) for G:F. The greatest G:F and ADG was achieved for pigs fed a Lys:Cal ratio of 4.55 for pigs fed the low ME diets and

4.29 for pigs fed the high ME diets. Results of these studies suggest pigs reared in this experimental environment were not in an energy dependent growth phase because of the lack of ADG response to higher energy density. Therefore these pigs needed approximately 10 g/d of TID Lys (20 g Lys per kg gain) to optimize ADG and G:F. Based on these results, the optimal Lys:Cal ratio may differ depending on feed intake of the pig.

Key Words: Lysine, energy, nursery pigs, growth

INTRODUCTION

It is commonly known that feed intake by the growing pig is generally determined by the energy density of the diet (NRC, 1998). Therefore, it is appropriate to change the proportion of dietary amino acids if the dietary energy density or feed intake is altered. The Lys requirement for growing-finishing pigs is commonly expressed as a lysine:calorie (**Lys:Cal**) ratio. This allows the Lys requirements to suitable over a wide range of dietary energy levels (De La Llata et al., 2001, Main et al., 2005).

Because of the cost of energy and amino acid sources in diet formulation, several attempts have been made to determine the optimal Lys:Cal ratio for maximizing growth in young rapidly growing pigs. Urynek and Buraczewska (2003) suggest that pigs from 13 to 30 kg should be fed diets containing 14.5 MJ (3.46 Mcal) of ME/kg with an apparent ileal digestible Lys:Cal ratio of 0.85 g/MJ (3.55 g of Lys/Mcal). These results are similar to Nam and Aherne (1994) who determined that 0.95 g of Lys/MJ DE (3.97 g Lys/Mcal DE) was optimum for weanling pigs (9 to 26 kg) fed low-energy, barley-based diets. However, Smith et al. (1999) suggested pigs weighing from 10 to 25 kg require at least 4.35 g of Lys/Mcal of ME. Many factors may be responsible for the variation in requirement (Smith et al., 1999) such as genetics, nutritional, physiological, and environmental (Pluske, 1995).

Therefore, our objective of these experiments were to first determine an optimal Lys:Cal ratio for maximal growth and feed efficiency of the 10 to 20 kg pig by titrating true ileal digestible (**TID)** Lys and energy levels simultaneously, and then validate the Lys:Cal ratio by titrating TID Lys at two energy levels.

MATERIALS AND METHODS

Animals, Housing, and Measurements.

Procedures used in these experiments were approved by the Kansas State University Animal Care and Use Committee. At weaning, pigs were transported for approximately 8 h to the Segregated Early-Weaning Research Nurseries at Kansas State University. Pigs were housed at the Kansas State University Segregated Early-Weaning facility. This facility was environmentally regulated to maintain animal comfort and the initial temperature (34ºC) was reduced by 1.5ºC each week. All pens (1.8 m^2) contained woven wire flooring and held five pigs. Pigs were given ad libitum access to feed and water through a dry feeder and one nipple water per pen. At the start of the trial, pigs were allotted by initial BW and randomly assigned to dietary treatments. From d 0 to 14 after weaning, pigs were fed a corn-soybean meal-based diet with 6.7% spray-dried animal plasma, 25% dried whey, 5.0% choice white grease, and formulated to contain 1.56% TID Lys and 3,465 kcal ME/kg. From d 14 to 21 after weaning, pigs were fed a corn-soybean meal based diet with 10% dried whey, 2.5% spray-dried blood meal, 3.0% choice white grease, and formulated to contain 1.35% TID Lys and 3,417 kcal ME/kg.

Experiment 1 and 2.

A total of 711 nursery pigs (Exp. 1, Genetiporc, initial BW = 10.2 kg, n = 360; Exp. 2, PIC, initial BW = 9.3 kg, n = 351) were used in a 21 d growth trial to determine an optimal Lys:Cal ratio. Pigs were allotted by BW in a randomized complete block design to one of nine diets with eight replicate pens per treatment. Each pen in Exp. 1 had five pigs per pen while in Exp. 2 each pen had four or five pigs per pen with an equal number of pigs per pen within replicate. Pigs and feeders were weighed on d 7, 14, and 21 to determine ADG, ADFI, and G:F.

Diets.

Both trials were organized as a combination of two separate titration experiments that evaluated Lys and energy density. There were one set of diets consisting of five treatments with increasing TID Lys (Exp. 1, 0.99, 1.07, 1.15, 1.22, and 1.30%; Exp. 2, 1.11, 1.19, 1.26, 1.34, and 1.42%; Tables 6.1 and 6.2) and the second set of diets consisting of five treatments with increasing energy density (Exp. 1, 2,952, 3,093, 3,236, 3,377, and 3,520 kcal of ME/kg; Exp. 2, 2,956, 3,130, 3,251, 3,399, and 3,547 kcal of ME/kg). The highest level of both Lys and energy density (Exp. 1, 1.30% and 3,520 kcal; Exp. 2, 1.42% and 3,547 kcal) diets were combined as one treatment and used in both Lys and energy density titrations to give a total of 10 treatments. The intermediate diets for the Lys titration experiments were formed by blending the different increments of the diets with the high and low levels of Lys (Exp. 1, 0.99 and 1.30%; Exp. 2, 1.11 and 1.42%), while the diets containing the high and low levels of energy (Exp. 1, 2,952 and 3,377 kcal; Exp. 2, 2,956 kcal and 3,547 kcal) were blended to form the intermediate diets for the energy titration experiments. The amount of soybean meal was constant among all titration diets (Exp. 1 = 31.90%; Exp. 2 = 36.66%). The TID Lys level was increased by adjusting the amount of L-lysine HCL, while the dietary energy density was increased by addition of soybean oil.

This was conducted to validate that the growth response in the Lys and energy titration experiments is due to the increasing amounts of Lys and energy density, not differences in biological value among the diets. All experimental diets were corn-soybean meal based and were fed in a meal form. Ingredient nutrient values from the NRC (1998) were used in formulation of treatment diets.

Experiment 3 and 4.

A total of 700 nursery pigs (Exp. 3, Genetiporc, initial BW = 9.4 kg, n = 350; Exp. 4, PIC, initial BW = 7.5 kg, n = 350) were used in a 21 d growth trial to evaluate the effects of increasing energy density and Lys:Cal ratio on growth performance. Pigs were allotted by BW in a randomized complete block design to one of 10 treatments in a 2 × 5 factorial arrangement. The factorials consisted of two energy density levels and five levels of Lys:Cal ratio. Seven replicate pens were used per treatment with five pigs per pen. Pigs and feeders were weighed on d 7, 14, and 21 to determine ADG, ADFI, and G:F.

Diets.

Pigs were fed a corn-SBM based diets with increasing energy densities (2.95 or 3.29 Mcal ME/kg) and increasing TID Lys:Cal ratios ranging from 3.1 to 4.1 g/Mcal ME in Exp. 1, and 3.5 to 4.5 g/Mcal ME in Exp. 2 (Tables 6.3 and 6.4). Energy density was changed by addition of sand (10%) to the diet containing 3.29 Mcal ME/kg. The Lys:Cal ratio was increased by adjusting the ratio of L-Lys HCl with an attempt made to keep the ratio of soybean meal (Exp. 1, 29.10 and 33.10%; Exp. 2, 34.07 and 38.66%, respectively) to corn similar among the two energy densities. This was conducted to make sure the growth response in this experiment is due to the increasing amounts of energy density in the diet and Lys:Cal ratios, not differences in biological value among the diets. The intermediate diets with increasing Lys:Cal ratios were formed by blending different increments of the diets with the high and low levels of Lys:Cal ratio (Exp. 3, 3.08 and 4.13, 3.13 and 4.07; Exp. 4, 3.50 and 4.55, 3.55 and 4.49, respectively). All experimental diets were corn-soybean meal-based and were fed in a meal form. Ingredient nutrient values from the NRC (1998) were used in formulation of treatment diets.

Statistical Analysis.

Data were analyzed as a randomized complete block design using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Blocks were based on initial weight, and pen served as the experimental unit for all response criteria. In Exp. 1 (Tables 6.5 and 6.6) and 2 (Tables 6.7 and 6.8), the model included the fixed effect of treatment and the random effect of block. In Exp. 1 and 2, the linear and quadratic polynomials were used to evaluate the increasing Lys level and energy densities.

In Exp. 3 (Table 6.9) and 4 (Table 6.10), the statistical model included the fixed effect of treatment and block as the random effect. The analysis included the main effect of energy density and Lys:Cal ratio as well as the interactive effects of energy density and Lys:Cal ratio (Tables 6.11 and 6.12). Linear and quadratic contrasts were used to evaluate the increasing Lys:Cal ratios within each energy level.

Three different methods were used to analyze the response criteria for Exp. 1 and 2. The first estimate was obtained using a one-slope broken-line regression model using the NLIN procedure of SAS. The second estimate was determined by establishing the first point where the quadratic curve intersected the broken-line (above the breakpoint) as described by Parr et al. (2003). The third estimate was based on the 95% quadratic maximum calculated from the quadratic model. The one-slope broken-line regression model and 95% quadratic maximum calculated from the quadratic model was used to evaluate the growth performance in Exp. 3 and 4 due to the inability for the broken-line to cross the quadratic curve above the breakpoint.

RESULTS

Experiment 1.

Overall (d 0 to 21), ADG increased (linear, $P < 0.01$; Table 6.5), while there was no difference in ADFI as TID Lys increased from 0.99 to 1.30%. However the highest ADG was for pigs fed the 1.22% TID Lys. Pigs fed increasing TID Lys also had increased (linear, $P < 0.01$) G:F, TID Lys intake, and TID Lys per kg/gain. As dietary energy increased, there was a tendency (quadratic, $P < 0.14$) for improved ADG, with the maximum level for pigs fed 3,093 ME kcal/kg (Table 6.6). However, ADFI decreased (linear, $P < 0.01$) and G:F increased (quadratic, $P < 0.05$) as the energy density increased. Pigs fed increasing dietary energy had decreased TID Lys intake (linear, $P < 0.01$) and TID Lys per kg/gain (quadratic, $P < 0.01$). Based on growth performance, using the one-slope broken-line model, the first x-intercept value of the broken-line and quadratic model, and 95% of quadratic maximum, the optimal TID Lys requirements for ADG was 1.25, 1.27, and 1.24%; G:F was 1.21, 1.22, and 1.19%. Based on growth performance, using the one-slope broken-line model, the first x-intercept value of the broken-line and quadratic model, and 95% of quadratic maximum, the optimal energy density requirements for ADG was 3,042, 3,090, and 3,080 kcal ME; G:F was 3,202, 3,280, 3,307 kcal ME. Thus, a TID Lys:Cal ratio based on ADG was 4.11, 4.11, 4.01 g Lys per Mcal ME whereas G:F was 3.78, 3.72, 3.59 g Lys per Mcal ME.

Experiment 2.

Overall (d 0 to 21), increasing TID Lys increased (linear, $P < 0.01$; Table 6.7) ADG, TID Lys intake, and TID Lys per kg/gain. While ADFI was not affected by dietary treatments, G:F improved (linear, $P < 0.01$) during this period. As dietary energy increased, there was a tendency (linear, $P < 0.11$) for decreased ADG, with the maximum level for pigs fed 2,952 ME kcal/kg (Table 6.8). However, ADFI, TID Lys intake, and TID Lys per kg/gain during this period was reduced (linear, $P < 0.01$), while G:F improved (linear, $P < 0.01$). Due to the inability of the one-slope broken-line model to identify an adequate breakpoint for ADG the values of G:F were used to predict a TID Lys:Cal ratio. Based on growth performance, using the one-slope broken-line model, the first x-intercept value of the broken-line and quadratic model, and 95% of quadratic maximum, the optimal TID Lys requirements for G:F was 1.37, 1.37, and 1.35%. Based on growth performance, using the one-slope broken-line model, the first x-intercept value of the broken-line and quadratic model, and 95% of quadratic maximum, the optimal energy density requirements for G:F was 3,246, 3,320, 3,369 kcal ME. Thus a TID Lys:Cal ratio based on G:F was 4.22, 4.13, 4.00 g Lys per Mcal ME.

Experiment 3.

Overall (d 0 to 21), there was an energy density × Lys:Cal ratio interaction observed for ADG and TID Lys intake ($P < 0.03$; Tables 6.9 and 6.10). Increasing energy density decreased ADFI ($P < 0.01$) and improved ($P < 0.01$) G:F. Increasing Lys:Cal ratio also decreased ($P < 0.06$) ADFI and increased ($P < 0.01$) G:F and TID Lys per kg/gain. Pigs fed the diets containing 2.95 Mcal of ME per kg had improved (quadratic, $P < 0.06$) ADG to an increasing Lys:Cal ratio with the greatest ADG for pigs fed the diet with 3.60 g TID Lys per Mcal ME. Pigs fed the diets containing 3.29 Mcal of ME per kg had improved (quadratic, $P < 0.01$) ADG to an increasing

Lys:Cal ratio with the maximum response at 3.35 g TID Lys per Mcal ME. Pigs fed the 2.95 Mcal of ME per kg diets had improved (quadratic, $P < 0.01$) G:F and increased (quadratic, $P < 0.06$) ADG, (linear, $P < 0.01$) TID Lys intake , (quadratic, $P < 0.01$) TID Lys per kg/gain as the Lys:Cal ratio increased. Pigs fed the diets containing 3.29 Mcal of ME per kg tended to have decreased (linear, $P < 0.03$) ADFI and increased (quadratic, $P < 0.07$) G:F, TID Lys intake (quadratic, $P < 0.10$), and TID Lys per kg/gain (linear, $P < 0.01$) as the Lys:Cal ratio increased. Based on the models used in this experiment the averaged estimated TID Lys:Cal ratio for optimal ADG and G:F was 3.87 and 3.68 g TID Lys per Mcal ME for the diet containing 2.95 Mcal/kg of ME. The averaged TID Lys:Cal ratio for optimal ADG and G:F for the diet containing 3.29 Mcal/kg of ME was estimated to be 3.42 and 3.66 g TID Lys per Mcal ME.

Experiment 4.

There was an ME × Lys:Cal interaction for G:F ($P < 0.08$; Tables 6.11 and 6.12) and TID Lys per kg/gain ($P < 0.05$) over the 21 d growth assay. Furthermore, there was a significant main effect of Lys:Cal ratio for ADG ($P < 0.01$) and TID Lys intake per day ($P < 0.01$). Pigs fed the diet containing 2.95 Mcal of ME per kg had improved (linear, $P < 0.01$) ADG as the Lys:Cal ratio increased with little improvement seen after 4.29 g TID Lys per Mcal ME. Average daily feed intake was not affected by increasing the Lys:Cal ratio; however, increasing the energy content from 2.95 to 3.29 Mcal/kg ME lowered ($P < 0.01$) ADFI. Increasing the Lys:Cal ratio for pigs fed the diet containing 2.95 Mcal of ME improved G:F (quadratic, $P < 0.03$), while there was a linear ($P < 0.01$) response in feed efficiency as the Lys:Cal ratio increased for pigs fed the 3.29 Mcal ME diet. Pigs fed both energy density diets tended to increase (linear and quadratic, $P < 0.01$) TID Lys intake as the Lys:Cal ratio increased. True ileal digestible Lys per kg/gain increased for pigs fed both energy density diets (linear and quadratic, $P < 0.01$) with approximately 18 to 20 grams of TID Lys needed per kilogram of gain. Based on the models used in this experiment the average estimated TID Lys:Cal ratio for optimal ADG and G:F was 4.43 and 4.30 g TID Lys per Mcal ME for the diet containing 2.95 Mcal/kg of ME. The averaged TID Lys:Cal ratio for optimal ADG and G:F for the diet containing 3.29 Mcal/kg of ME was estimated to be 3.93 and 4.16 g TID Lys per Mcal ME.

DISCUSSION

The NRC (1998) estimated the TID Lys requirement for the 10 to 20 kg pig is 1.01%. However, the dietary TID Lys requirement may be higher for the modern pig because of the increased rate of protein deposition and feed efficiency from improved genetics. Gaines et al. (2003) suggested that to obtain maximum ADG and G:F, 1.42 and 1.52%, TID Lys, respectively, is requiremed. Furthermore, Lenehan et al. (2003) estimated the TID Lys requirement at 1.40% for maximum growth performance of the 10 to 20 kg pig. Yi et al. (2006) indicated a TID Lys requirement of 1.28 and 1.32% for maximum ADG. These results were consistent with previous suggestions of a TID Lys requirement of 1.32% for the 11 to 29 kg pigs (Fu et al., 2004) and 1.33% for 11 to 25 kg pigs (Kendall et al., 2002). After reviewing a large body of literature, Le Bellego et al. (2002) estimated the TID Lys requirement of 5 to 25 kg pigs with ADG of 500 and 600 g to be 1.21 and 1.40%, respectively. Hill et al. (2005) in the NCCC-42 Committee on Swine Nutrition reported that the Lys requirement to be at least 0.2% greater than NRC (1998) recommendation for 7 to 23 kg pigs regardless of genotype, sex, and experimental locations. In an AA titration experiment, Schneider (unpublished data) using similar analysis showed the Lys requirement of the Genetiporc pig for optimal ADG to be 1.03, 1.17, and 1.24% and G:F to be 1.06, 1.19, 1.11%, respectively. In a separate TSAA titration experiment (Schneider, unpublished data) using similar analysis reported the Lys requirement of the PIC pig for optimal ADG to be 1.17, 1.25, and 1.28% and G:F to be 1.22, 1.29, and 1.34%, respectively. In the present data the one-slope broken-line model, the first x-intercept value of the broken-line and quadratic model, and 95% of quadratic maximum predicted the TID Lys requirements for optimal G:F for Genetiporc and PIC pigs to be 1.21, 1.22, and 1.19% and 1.37, 1.37, and 1.35%, respectively The results from this trial and reviews of other manuscripts have shown that the requirement for TID Lys is higher than the NRC (1998) estimate for the modern pig and that estimates between genetic lines may vary.

According to Beaulieu et al. (2006) the effects on growth performance by increasing the dietary energy density for the weanling pig is conflicting. This may be due to the age of the pig (Tokach et al., 1995), reduction in social stressors related to available feeder space, or the difference between formulated and measured dietary energy values (Beaulieu et al., 2006). The NRC (1998) estimates that the 15 kg pig require 3,265 kcal/kg of ME for adequate ADG. Also, Smith et al. (1999) suggested that the 10 to 25 kg pigs should be fed diets containing 3,380 kcal/kg of ME to maximize G:F. The data in this trial was similar with an estimated dietary energy level of 3,263 kcal/kg of ME for required optimal G:F in Genetiporc pigs. Optimal G:F for PIC pigs in this study was estimated to be 3,312 kcal/kg of ME. It should be noted that these performance responses were derived in a controlled environment with five pigs per pen and feed intake may be different across genetic lines and production environments.

Main (2005) asserted that even within a given gender and genetic line, the level of feed intake (and associated growth rate or protein deposition) may be a source of inconsistency with the reported lysine requirement estimate across studies. Furthermore, Mohn et al. (2000) concluded that lysine intake does not affect protein deposition if energy intake is limiting and energy intake does not affect protein deposition when lysine is limiting. For example, the Lys:Cal ratio required for optimal performance will differ when pigs with a high genetic potential for protein deposition is limited in energy intake, due to health status or production constraints, versus the same genetic line and gender consuming higher levels of energy (Main, 2005). This may be caused by a higher proportion of energy going toward maintenance and less towards protein deposition. There are many inputs and selection criteria that may influence the Lys:Cal ratio such as feed intake (Mohn et al., 2000), composition of growth (Schinckel and De Lange, 1996; Friesen et al., 1996; Smith et al., 1999), and interpreting biological or economical responses (Gahl et al., 1995; De La Llata et al., 2001). However, attempting to discuss the Lys:Cal ratio estimate across multiple studies is not appropriate as the correct answer will vary across genetics and production facilities (Main, 2005). Using the G:F data in this study the various models estimated a TID Lys:Cal ratio for the Genetiporc and PIC pig to be approximately 3.70 and 4.13 , respectively.

According to Smith et al. (1999) economically minded producers are concerned about the dietary energy and amino acid costs. Thus various researchers have attempted to determined the appropriate Lys:Cal ratio of specific dietary energy levels. In Exp. 3 and 4, ADFI was decreased by increasing the dietary energy from 2.95 to 3.29 Mcal/ kg of ME. Similarly, Nam and Aherne (1994) and Smith et al. (1999) observed decreased ADFI as the dietary energy increased. However, in experiments by Urynek and Buraczewska (2003), Campbell and Taverner (1988), and Zhang et al. (1984) found no difference in ADFI. Furthermore, Beaulieu et al. (2006) determined that pigs on ad libitum feed intake experienced similar overall energy intake (DE intake of 2.34, 2.30, and 2.45 Mcal/d) when fed diets containing 3.35, 3.50, and 3.65 Mcal/kg.

A Lys:Cal ratio × energy density interaction for ADG was detected in Exp. 3, but an interaction was not detected in Exp. 4. This response may be related to growth rate in these experiments. In Exp. 3, the pigs fed the 3.29 ME diet reach their maximum ADG at a Lys:Cal ratio of 3.35 while the pigs fed the 2.95 ME diet was at a higher Lys:Cal ratio. Previous research has shown mixed results when studying a Lys:Cal × energy density interaction for ADG. Smith et al. (1999) detected an interaction for ADG over a 21 d experiment; however, this is not consistent with findings from other experiments with pigs of similar weight pigs (Urynek and Buraczewska, 2003; Nam and Aherne, 1994). In heavier pigs (20 to 50 kg), Chiba et al. (1991) also did not detect an Lys:Cal × energy density interaction. In Exp. 3, increasing the Lys:Cal ratio in both the low and high energy diet produced an increase in ADG and improved G:F. In Exp. 4, increasing the Lys:Cal ratio in the diet containing 2.95 ME Mcal/kg linearly increased ADG and improved G:F. However, this response in ADG was not seen as the Lys:Cal ratio increased in the diet containing 3.29 ME Mcal/kg. Although increasing the Lys:Cal ratio improved feed efficiency in both the low and high energy diet.

Much research has been conducted to examine the optimum Lys:Cal ratio to improve growth performance. Martinez and Knabe (1990) estimated the appropriate ratio for the 6 to 20 kg pig to be 3.86 g Lys:Cal ME. Williams et al. (1997) suggested that the 6 to 27 kg pig with a high health status should be fed diets containing a 4.72 Lys:Cal ratio, while immune challenged pigs require a 3.77 Lys:Cal ratio. Owen (1996) suggested that pigs (18 to 23.5 kg) with high health status required a Lys:Cal ratio in excess of 4.45 g Lys:Cal ME. This is similar to the work of Smith et al. (1999) that proposed an optimum ratio of 4.45 g Lys:Cal ME. Nam and Aherne (1994) suggested that pigs fed a barley-wheat based diet required 3.97 g Lys:Cal DE (3.81 g Lys:Cal ME). However, the lower Lys:Cal ratio in the Nam and Aherne (1994) study is most likely related to the inability of the pig to consume enough energy to maximize growth rate. In Exp. 3, the optimal TID Lys:Cal ratio for ADG and G:F were 3.87 and 3.68 g Lys per Mcal ME for Genetiporc pigs fed the diet containing 2.95 Mcal/kg ME. The optimal TID Lys:Cal ratio for ADG and G:F were 3.42 and 3.66 g Lys per Mcal ME for Genetiporc pigs fed the diet containing 3.29 Mcal/kg ME. The resulting optimal TID Lys:Cal ratios for the Genetiporc pig fed both energy levels in Exp. 3 were similar to the estimated ratios in Exp. 1. In Exp. 4, the optimal TID Lys:Cal ratio for ADG and G:F were 4.43 and 4.30 g Lys per Mcal ME for PIC pigs fed the diet containing 2.95 Mcal/kg ME. The optimal TID Lys:Cal ratio for ADG and G:F were 3.92 and 4.16 g Lys per Mcal ME for PIC pigs fed the diet containing 3.29 Mcal/kg ME. The optimal TID Lys:Cal ratio in the 3.29 Mcal/kg ME diet were similar to the estimated TID Lys:Cal ratio of 4.13 in Exp. 2. However, the optimal ratio in the 2.95 Mcal/kg ME diet was higher than the estimated ratio and may be due to linear response for ADG.

In the present study, attempts were made to suggest the grams of TID Lys needed per kilogram of gain. According to Main (2005) if a specific growth rate within a production system is know for a given genetic line, an appropriate Lys:Cal ratio may be established. Thus, producers may be able to estimate the optimum Lys:Cal ratio based on dietary energy costs and production goals. The overall trend in these trials indicate that the TID Lys intake per kilogram of gain was fairly consistent (≈ 20 g TID Lys/kg of gain) at the Lys:Cal ratio that optimized G:F between the different energy levels and genetics. This was similar to the reports by Main (2005) and De La Llata et al. (2000, 2001) which showed that growing pigs in a commercial environment need roughly 20 g TID Lys per kg of gain to maximize growth performance. However, pigs only required approximately 18 g of Lys per kg of gain at the optimal Lys:Cal that is suggested by Smith et al. (1999). Although Lys intake expressed as grams of TID Lys intake per kg of gain is a retrospective association between Lys intake and growth (Main, 2005), it can be a tool for producers to help formulate a Lys:Cal ratio requirement in swine diets if the approximate intake is known.

Understanding the effects on increasing the dietary energy and Lys on growing pig performance is a central issue in developing cost effective feeding strategies. Although Lys and energy has been well studied, it is generally understood that genetics may influence an optimum Lys:Cal regimen. This study has shown that Genetiporc and PIC influenced pigs need approximately 20 g TID Lys per kg of gain to optimize growth performance in this production system. Nutritionists may be able to formulate diets to allow the needed Lys intake based on available dietary energy density and knowledge of the production system feed intake. However, feed wastage should be accounted for when trying to estimate a nutrient requirement using an amount of nutrient per day or unit gain.

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Table 6.1 Composition of experimental diets (as-fed basis) (Exp. 1)

	TID lysine (%)/ME (Mcal)		
Item, %	0.99/3.52[1]	1.30/3.52[12]	1.30/2.95[2]
Corn	59.69	58.90	53.90
Soybean meal (46.5% CP)	31.91	31.90	31.90
Soybean oil	5.00	5.00	---
Sand	---	---	10.00
Monocalcium P (21% P, 18% Ca)	1.25	1.25	1.25
Limestone	0.90	0.90	0.90
Salt	0.35	0.35	0.35
Trace mineral premix[3]	0.15	0.15	0.15
Vitamin premix[4]	0.25	0.25	0.25
Antibiotic[5]	0.50	0.50	0.50
DL-methionine	---	0.20	0.20
L-threonine	---	0.20	0.20
L-Lysine HCL	---	0.40	0.40
Total	100.00	100.00	100.00
Calculated composition			
CP, %	19.9	19.8	19.7
Ca, %	0.70	0.70	0.70
Available P, %	0.34	0.34	0.33
Analyzed composition			
CP, %	19.3	22.2	20.6
Total Lys, %	1.13	1.47	1.42
Total Thr, %	0.80	0.94	0.95
TSAA, %	0.72	0.81	0.67

[1]The diet that contained 0.99% true ileal digestible (TID) Lys and 3.52 Mcal ME was blended with the diet that contained 1.30% TID Lys and 3.52 Mcal ME to achieve the intermediate diets with TID Lys levels of 1.07, 1.15, and 1.22%.

[2]The diet that contained 1.30% TID Lys and 2.95 Mcal ME was blended with the diet that contained 1.30% TID Lys and 3.52 Mcal ME to achieve the intermediate diets with ME levels of 3.09, 3.24, and 3.38 Mcal.

[3]Provided (per kilogram of complete diet): 36.04 mg of Mn; 150.18 mg of Fe; 150.18 mg of Zn; 15.02 mg of Cu; 0.27 mg of I; and 0.27 mg of Se.

[4]Provided (per kilogram of complete diet): 10,012 IU of vitamin A; 1,502 IU of vitamin D_3; 40 IU of vitamin E; 4.0 mg of vitamin K; 45.05 mg of niacin; 25.03 mg of pantothenic acid; 7.5 mg of riboflavin; and 0.035 mg of B_{12}.

[5]Provided 11.36 mg of carbadox per kg of complete diet.

Table 6.2 Composition of experimental diets (as-fed basis) (Exp. 2)

Item, %	TID lysine (%)/ME (Mcal) 1.11/3.54[1]	1.42/3.55[12]	1.42/2.96[2]
Corn	54.94	54.15	49.15
Soybean meal (46.5% CP)	36.66	36.65	36.65
Soybean oil	5.00	5.00	---
Sand	---	---	10.00
Monocalcium P (21% P, 18% Ca)	1.25	1.25	1.25
Limestone	0.90	0.90	0.90
Salt	0.35	0.35	0.35
Trace mineral premix[3]	0.15	0.15	0.15
Vitamin premix[4]	0.25	0.25	0.25
Antibiotic[5]	0.50	0.50	0.50
DL-methionine	---	0.20	0.20
L-threonine	---	0.20	0.20
L-Lysine HCL	---	0.40	0.40
Total	100.00	100.00	100.00
Calculated composition			
CP, %	21.7	21.6	21.2
Ca, %	0.71	0.71	0.71
Available P, %	0.34	0.34	0.34
Analyzed composition			
CP, %	21.3	21.4	21.5
Total Lys, %	1.24	1.57	1.55
Total Thr, %	0.83	1.06	1.04
TSAA, %	0.77	0.94	0.92

[1]The diet that contained 1.11% true ileal digestible (TID) Lys and 3.54 Mcal ME was blended with the diet that contained 1.42% TID Lys and 3.55 Mcal ME to achieve the intermediate diets with TID Lys levels of 1.19, 1.26, and 1.34%.

[2]The diet that contained 1.42% TID Lys and 2.96 Mcal ME was blended with the diet that contained 1.42% TID Lys and 3.55 Mcal ME to achieve the intermediate diets with ME levels of 3.10, 3.25, and 3.40 Mcal.

[3]Provided (per kilogram of complete diet): 36.04 mg of Mn; 150.18 mg of Fe; 150.18 mg of Zn; 15.02 mg of Cu; 0.27 mg of I; and 0.27 mg of Se.

[4]Provided (per kilogram of complete diet): 10,012 IU of vitamin A; 1,502 IU of vitamin D_3; 40 IU of vitamin E; 4.0 mg of vitamin K; 45.05 mg of niacin; 25.03 mg of pantothenic acid; 7.5 mg of riboflavin; and 0.035 mg of B_{12}.

[5]Provided 11.36 mg of carbadox per kg of complete diet.

Table 6.3 Composition of diets (as-fed basis) (Exp. 3)

	Energy density, Mcal ME/kg			
	2.95		3.29	
	Lysine:calorie ratio, g/Mcal			
Item, %	3.08[1]	4.13[1]	3.13[2]	4.07[2]
Corn	57.39	56.57	63.39	62.61
Soybean meal (46.5% CP)	29.10	29.10	33.10	33.10
Sand	10.00	10.00	---	---
Monocalcium P (21% P, 18% C)	1.35	1.35	1.35	1.35
Limestone	0.90	0.90	0.90	0.90
Salt	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.25	0.25	0.25	0.25
Trace mineral premix[4]	0.15	0.15	0.15	0.15
L-Lysine HCL	---	0.40	---	0.40
DL-methionine	0.01	0.20	0.01	0.20
L-valine	---	0.02	---	---
L-isoleucine	---	0.01	---	---
L-tryptophan	---	0.01	---	---
L-threonine	---	0.19	--	0.19
Antibiotic[5]	0.50	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00
Calculated composition				
CP, %	18.40	18.30	20.80	20.70
Ca, %	0.71	0.71	0.72	0.72
Available P, %	0.35	0.35	0.36	0.36
Analyzed composition				
CP, %	18.00	18.50	21.30	20.90
Total Lys, %	1.05	1.35	1.18	1.50
Total Thr, %	0.73	0.86	0.82	0.97
TSAA, %	0.66	0.85	0.70	0.93

[1]The diet that contained a 3.08 true ileal digestible (TID) Lys:Calorie (Lys:Cal) ratio was blended with the diet that contained a 4.13 TID Lys:Cal ratio to achieve the intermediate diets with TID LysCal ratios of 3.34, 3.60, and 3.87 for the diet that was formulated to 2.95 Mcal ME.
[2]The diet that contained a 3.13 TID Lys:Cal ratio was blended with the diet that contained a 4.07 TID Lys:Cal ratio to achieve the intermediate diets with TID LysCal ratios of 3.39, 3.60, and 3.83 for the diet that was formulated to 3.29 Mcal ME.
[3]Provided (per kilogram of complete diet): 10,012 IU of vitamin A; 1,502 IU of vitamin D_3; 40 IU of vitamin E; 4.0 mg of vitamin K; 45.05 mg of niacin; 25.03 mg of pantothenic acid; 7.5 mg of riboflavin; and 0.035 mg of B_{12}.
[4]Provided (per kilogram of complete diet): 36.04 mg of Mn; 150.18 mg of Fe; 150.18 mg of Zn; 15.02 mg of Cu; 0.27 mg of I; and 0.27 mg of Se.
[5]Provided 11.36 mg of carbadox per kg of complete diet.

Table 6.4 Composition of diets (as-fed basis) (Exp. 4)

	Energy density, Mcal ME/kg			
	2.95		3.29	
	Lysine:calorie ratio, g/Mcal			
Item, %	3.50[1]	4.55[1]	3.55[2]	4.49[2]
Corn	52.41	51.58	57.82	57.82
Soybean meal (46.5%)	34.07	34.07	38.66	38.66
Sand	10.00	10.00	---	---
Monocalcium P (21% P, 18% C)	1.35	1.35	1.35	1.35
Limestone	0.90	0.90	0.90	0.90
Salt	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.25	0.25	0.25	0.25
Trace mineral premix[4]	0.15	0.15	0.15	0.15
L-Lysine HCL	---	0.40	---	0.40
DL-methionine	0.03	0.22	0.03	0.22
L-valine	---	0.03	---	0.03
L-isoleucine	---	--	---	---
L-tryptophan	---	0.01	---	0.01
L-threonine	---	0.20	---	0.20
Antibiotic[5]	0.50	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00
Calculated composition				
CP, %	20.30	20.20	22.90	22.80
Ca, %	0.72	0.72	0.74	0.74
Available P, %	0.36	0.36	0.37	0.37
Analyzed composition				
CP, %	20.50	20.60	23.10	22.60
Total Lys, %	1.15	1.50	1.35	1.66
Total Thr, %	0.80	1.02	0.88	1.11
TSAA, %	0.72	0.93	0.77	0.94

[1]The diet that contained a 3.50 true ileal digestible (TID) Lys:Calorie (Lys:Cal) ratio was blended with the diet that contained a 4.55 TID Lys:Cal ratio to achieve the intermediate diets with TID LysCal ratios of 3.77, 4.03, and 4.29 for the diet that was formulated to 2.95 Mcal ME.
[2]The diet that contained a 3.55 TID Lys:Cal ratio was blended with the diet that contained a 4.49 TID Lys:Cal ratio to achieve the intermediate diets with TID LysCal ratios of 3.79, 4.03, and 4.26 for the diet that was formulated to 3.29 Mcal ME.
[3]Provided (per kilogram of complete diet): 10,012 IU of vitamin A; 1,502 IU of vitamin D_3; 40 IU of vitamin E; 4.0 mg of vitamin K; 45.05 mg of niacin; 25.03 mg of pantothenic acid; 7.5 mg of riboflavin; and 0.035 mg of B_{12}.
[4]Provided (per kilogram of complete diet): 36.04 mg of Mn; 150.18 mg of Fe; 150.18 mg of Zn; 15.02 mg of Cu; 0.27 mg of I; and 0.27 mg of Se.
[5]Provided 11.36 mg of carbadox per kg of complete diet.

Table 6.5 Effect of increasing TID lysine for the nursery pig (Exp. 1)[12]

	True ileal digestible (TID) lysine, %						*P*-value (*P* <)	
Item	0.99	1.07	1.15	1.22	1.30	SE	Linear	Quadratic
Day 0 to 21								
ADG, g	547	556	574	587	586	18.11	0.01	0.58
ADFI, g	909	887	900	912	896	31.60	0.99	0.86
G:F	0.60	0.63	0.64	0.65	0.66	0.01	0.01	0.29
TID Lys intake, g/d	8.98	9.45	10.31	11.15	11.66	0.38	0.01	0.94
TID Lys gain, g/kg	16.66	17.15	18.01	18.98	19.86	0.36	0.01	0.61

[1]Each value is the mean of eight replications with five pigs (initially 10.2 kg, Gentiporc) per pen.
[2]All diets with increasing true ileal digestible (TID) Lys levels were formulated to be iso-caloric with 3,520 kcal.

Table 6.6 Effect of increasing energy density for the nursery pig (Exp. 1)[12]

	Dietary ME, kcal/kg						*P*-value (*P* <)	
Item	2,952	3,093	3,236	3,377	3,520	SE	Linear	Quadratic
Day 0 to 21								
ADG, g	573	607	597	585	586	18.11	0.90	0.14
ADFI, g	1058	1019	966	923	896	31.60	0.01	0.62
G:F	0.55	0.61	0.63	0.64	0.66	0.01	0.01	0.05
TID Lys intake, g/d	13.65	13.17	12.52	11.98	11.66	0.38	0.01	0.51
TID Lys gain, g/kg	23.75	21.60	20.83	20.49	19.86	0.36	0.01	0.01

[1]Each value is the mean of eight replications with 5 pigs (initially 10.2 kg, Gentiporc) per pen.
[2]All diets with increasing dietary ME were formulated to a true ileal digestible (TID) Lys level of 1.30%.

Table 6.7 Effect of increasing TID lysine for the nursery pig (Exp. 2)[12]

	True ileal digestible (TID) lysine, %						*P*-value (*P* <)	
Item	1.11	1.19	1.26	1.34	1.42	SE	Linear	Quadratic
Day 0 to 21								
ADG, g	555	573	573	588	598	22.05	0.01	0.98
ADFI, g	805	800	805	783	795	37.41	0.58	0.94
G:F	0.70	0.72	0.73	0.76	0.76	0.02	0.01	0.70
TID Lys intake, g/d	8.93	9.53	10.14	10.49	11.29	0.51	0.01	0.90
TID Lys gain, g/kg	16.39	16.62	17.85	17.79	18.94	0.39	0.01	0.92

[1]Each value is the mean of eight replications with four or five pigs (initially 9.3 kg, PIC) per pen with an equal number of pigs per pen within replicate.
[2]All diets with increasing true ileal digestible (TID) Lys levels were formulated to be iso-caloric with 3,543 kcal.

Table 6.8 Effect of increasing energy density for the nursery pig (Exp. 2)[12]

	Dietary ME, kcal/kg						*P*-value (*P* <)	
Item	2,952	3,103	3,251	3,399	3,547	SE	Linear	Quadratic
Day 0 to 21								
ADG, g	621	619	613	604	598	22.05	0.11	0.83
ADFI, g	929	885	872	820	795	37.41	0.01	0.99
G:F	0.69	0.72	0.71	0.75	0.76	0.02	0.01	0.99
TID Lys intake, g/d	13.10	12.48	12.38	11.64	11.29	0.51	0.01	0.68
TID Lys gain, g/kg	21.39	20.06	20.14	19.20	18.94	0.39	0.01	0.41

[1]Each value is the mean of eight replications with four or five pigs (initially 9.3 kg, PIC) per pen with an equal number of pigs per pen within replicate.
[2]All diets with increasing dietary ME were formulated to a TID Lys level of 1.42%.

Table 6.9 Effects of increasing energy density and lysine:calorie ratio on nursery pig performance (Exp. 3)[12]

	Lysine:Calorie ratio, g/Mcal[123]						P-value (P <)	
Item	3.10	3.35	3.60	3.85	4.10	SE	Linear	Quadratic
2.95 ME, Mcal/kg								
ADG, g	538	558	598	573	591	16.08	0.01	0.06
ADFI, g	1001	994	1035	966	1027	38.89	0.71	0.72
G:F	0.54	0.57	0.59	0.60	0.59	0.01	0.01	0.01
TID Lys intake, g/d	9.08	9.80	11.02	11.03	12.53	0.44	0.01	0.65
TID Lys gain, g/kg	16.97	17.46	18.28	19.20	21.05	0.37	0.01	0.01
3.29 ME, Mcal/kg								
ADG, g	547	594	589	565	570	16.08	0.58	0.01
ADFI, g	923	930	940	891	879	38.89	0.03	0.15
G:F	0.60	0.65	0.64	0.65	0.66	0.01	0.01	0.07
TID Lys intake, g/d	9.49	10.37	11.14	11.25	11.78	0.44	0.01	0.10
TID Lys gain, g/kg	17.24	17.27	18.73	19.75	20.7	0.37	0.01	0.20

[1]Each value is the mean of seven replications with five pigs (initially 9.4 kg, Gentiporc) per pen.
[2]Approximate true ileal digestible (TID) Lys:Calorie (Lys:Cal) ratio ranged from 3.10 to 4.10; Actual Lys:Cal ratio for diet containing 2.95 ME, Mcal/kg are the following: 3.08, 3.34, 3.60, 3.87, and 4.13 g/Mcal; Actual Lys:Cal ratio for diet containing 3.29 ME, Mcal/kg are the following: 3.13, 3.36, 3.60, 3.83, and 4.07 g/Mcal, respectively.

6.10 Probability of the main effects and interaction in Exp. 3[1]

	P-value (*P* <)		
Item	Energy Density (ME)	Lys:Calorie	ME × Lys:Calorie
ADG, g	0.78	0.01	0.03
ADFI, g	0.01	0.06	0.17
G:F	0.01	0.01	0.24
True ileal digestible Lysine intake, g/d	0.41	0.01	0.03
True ileal digestible Lysine gain g/kg	0.42	0.01	0.43

[1]Response criteria is the mean of seven replications with five pigs (initially 9.4 kg, Gentiporc) per pen.

Table 6.11 Effects of increasing energy density and lysine:calorie ratio on nursery pig performance (Exp. 4)[1,2]

	Lysine:Calorie ratio, g/Mcal						*P*-value (*P* <)	
Item	3.50	3.75	4.05	4.29	4.50	SE	Linear	Quadratic
2.95 ME, Mcal/kg								
ADG, g	449	455	470	503	509	20.42	0.01	0.71
ADFI, g	727	719	751	773	744	34.21	0.11	0.41
G:F	0.62	0.64	0.63	0.66	0.70	0.01	0.01	0.03
TID Lysine intake, g/d	7.50	7.98	8.93	9.80	10.01	0.44	0.01	0.46
TID Lysine gain, g/kg	16.81	17.79	19.12	19.67	19.55	0.80	0.01	0.01
3.29 ME, Mcal/kg								
ADG, g	466	482	478	504	479	20.42	0.26	0.31
ADFI, g	686	681	671	676	652	34.21	0.19	0.74
G:F	0.68	0.71	0.72	0.75	0.74	0.01	0.01	0.12
TID Lysine intake, g/d	8.02	8.49	8.88	9.48	9.66	0.44	0.01	0.66
TID Lysine gain, g/kg	17.51	17.88	18.74	18.83	20.23	0.80	0.01	0.25

[1]Each value is the mean of seven replications with five pigs (initially 7.5 kg, PIC) per pen.

[2]Approximate true ileal digestible (TID) Lysine:Calorie (Lys:Cal) ratio ranged from 3.50 to 4.50; Actual TID Lys:Cal ratio for diet containing 2.95 ME, Mcal/kg are the following: 3.50, 3.77, 4.03, 4.29, and 4.55 g/Mcal; Actual TID Lys:Cal ratio for diet containing 3.29 ME, Mcal/kg are the following: 3.55, 3.79, 4.03, 4.29, and 4.49 g/Mcal, respectively.

6.12 Probability of the main effects and interaction in Exp. 4[1]

	P-value (*P* <)		
Item	Energy Density (ME)	Lys:Calorie	ME × Lys:Calorie
ADG, g	0.61	0.01	0.28
ADFI, g	0.01	0.55	0.26
G:F	0.01	0.01	0.08
True ileal digestible Lysine intake, g/d	0.68	0.01	0.15
True ileal digestible Lysine gain g/kg	0.80	0.01	0.05

[1]Response criteria is the mean of seven replications with five pigs (initially 7.5 kg, PIC) per pen.