PROGENY RESPONSE IN LEAN TISSUE FEED CONVERSION TO SELECTION FOR POSTWEANING GAIN AMONG BOARS WITH LIMITED FEED INTAKE

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NOMENCLATURE

ADG	average daily gain
C	unselected control line
F	line selected for increased gain from 36 through 104 kg under ad libitum intake
F'	line from previous project selected for increased gain from 9 weeks of age through 100 kg
FFG	fall farrowing group (farrowed mid-September through October)
kg	kilogram
L	line selected for increased gain form 36 through 104 kg under a standard limited intake
LTFC	lean tissue feed conversion
LTGR	lean tissue growth rate
SFG	spring farrowing group (farrowed mid-March through April)

CHAPTER I

INTRODUCTION

The swine industry today is facing many challenging problems. The consumer in today's market place is concerned about excessive fat and an inconsistent product. Although retailers can trim external fat, it would be much more advantageous if we could eliminate trimmable fat genetically, without sacrificing overall production efficiency.

The swine industry is concerned with selecting those animals that most effectively convert nutrient intake into lean gain. Genetic improvements may be realized by two methods. These two methods are selection and crossbreeding. Genetic improvements in certain lines of pigs can only be accomplished by selecting for the traits of interest. Production of crossbred offspring offers advantages in two ways. These advantages include heterosis or 'hybrid vigor' and breed complementation. Breed complementation allows breeds to complement each other based on the strong points of each breed.

Terminal lines should focus on improving postweaning traits such as growth, efficiency and carcass quality. In a terminal crossbreeding system, the paternal or sire line will have genetic contributions for postweaning traits, but will not contribute to reproductive traits since all offspring by terminal sires are sold. Breeding programs for terminal lines therefore should stress improved lean gain and improved efficiency of lean growth.

Single-trait selection for growth and carcass traits has shown positive results in experimental lines of pigs. Selection for increased weight at a constant age (Krider et al., 1946; Kuhlers and Jungst, 1990; Kuhlers and Jungst, 1991ab) and for selection for average daily gain (Rahnefeld, 1971; Fredeen and Mikami, 1986; Woltmann et al., 1992) have been successful. However if selection focuses on one trait at a time there could be unfavorable responses in traits that are not under consideration for selection.

Several methods exist for selection of lean tissue growth rate either directly or indirectly. Index selection is one method that can be used to improve lean composition or lean growth rate. Positive response to index selection has been reported in a number of studies. An index containing only gain and backfat resulted in improvements in both traits (Vangen, 1974; Sather and Fredeen, 1977; Ollivier, 1980; Cleveland et al., 1982; McKay, 1990). Selection using this index generally resulted in improvements in lean growth rate and efficiency of lean growth. Selection on an index containing gain, backfat and feed conversion resulted in improvements in efficiency and backfat, but did not improve growth rate (McPhee, 1981; Henderson et al., 1982). The improvements made by this index were primarily a result of decreased appetite. A tendency to drive down average daily feed intake may increase production cost due to an extended time period on feed. Another method that has been proposed to avoid this downward pressure on feed intake is selection for increased ADG under scaled or restricted feeding (Fowler et al., 1976).

Fowler et al. (1976) proposed a more direct, biological model as a method of selection for lean tissue growth rate (LTGR) and lean tissue feed conversion (LTFC). He proposed selection for average daily gain under scaled or restricted feeding in an attempt to remove variation in intake. Selection at ad libitum intake allows intake to vary when selecting for gain. Thus much of the improvement in gain can be attributed to corresponding increases in appetite (Smith and Fowler, 1978).

McPhee et al. (1987) used the mouse as a model to compare selection for ADG under ad libitum versus limited intake. Selections were for six generations. The mice selected for ADG under limited intake had the greatest lean tissue conversion ratio regardless of the feeding level at which they were evaluated.

The selection lines evaluated in the present study were developed from a line of pigs that had been selected for ADG at ad libitum intake beginning in 1981 at the Southwest Livestock and Forage Research Station located near El Reno, OK. Selection criteria in the present study were 1) postweaning ADG among boars allowed ad libitum feed intake (F), 2) postweaning ADG among boars limited to 83% of predicted ad libitum feed intake (L), and 3) a relaxed selection control. The objectives of this study were to compare barrows sampled from the F, L and C lines at ad libitum intake and limited intake. Traits evaluated were lean tissue gain (LTGR), lean tissue feed conversion (LTFC) and component traits such as ADG, backfat and feed efficiency.

CHAPTER II

REVIEW OF LITERATURE

Selection

Selection is the practice of allowing certain individuals more of an opportunity to reproduce than others. It is the only way of making genetic improvement in a closed population. If we select to make improvements in traits then we are increasing the frequencies of the desirable genes that affect those traits. Selection is of two basic kinds. Natural selection or that due to natural forces and artificial or that due to the efforts of man.

Natural selection is a very complicated process, and many factors determine the proportion of individuals that will reproduce. Among these factors are differences in mortality of the individuals in the population, differences in the duration of the period of sexual activity itself and differences in the degree of fertility of individuals in the population (Lasley, 1987). Generally in the wild state there is a tendency toward an elimination of the detrimental genes that have arisen through mutation by means of the survival of the fittest. These genotypes may not even appear in the population.

Artificial selection is selection practiced by man kind. It may be defined as the efforts of man kind to increase the frequency of desirable genes or combinations of genes in his or her herd flock by locating and saving for breeding purposes those individuals with superior performance. Selection actually does not create new genes, but increases the frequency of desired gene forms (alleles).

Progress as a result of selection is called response. This is a genetic change that occurs as a result of selection. There are several different factors that determine response to selection both in the short run and long run.

Factors That Affect Response To Selection

Short Term

The response is a function of the heritability and the selection differential. Heritability is a very important concept in terms of livestock or animal improvement. It is defined as the proportion of the phenotypic variation which is due to additive gene effects. Dominance and interaction effects depend upon combinations of genes in pairs so they are not transferred from one generation to the next. Heritability also gives us some indication of the proportion of the superiority in an individual or in a group of individuals that can be passed on to the next generation. Heritability helps us to estimate breeding value and to predict response to selection. The most practical use of heritability is that it indicates how easy it is to make improvement through selection. Selection differential is defined as the difference between the mean performance of selected individuals and the average of the entire population. This actually assumes an equal number of males and females selected, however in reality with most livestock programs most of the selection pressure is applied on the male side.

Long Term

Without mutations creating new variation the response to selection cannot be expected to continue indefinitely (Falconer, 1989). Sooner or later the genes segregating in the base population will be brought to fixation by the selection or the accompanying inbreeding.

The total response relative to the initial genetic variation, depends primarily on the number of loci contributing to the variation. With larger numbers of loci, the extreme genotypes are rarer in the base population and the selection limits are further removed (Falconer, 1989).

New genetic variation is continually produced by mutation, but each new mutant has only a very limited effect in the next few generations after its occurrence. Selection can increase the frequency of favorable mutants so that they are not lost. As their frequencies are further increased by continued selection, the variance they produce increases and they contribute more to the response. New mutations are introduced at every generation so that the response per generation attributable to mutation gradually builds up over time and eventually reaches an amount that is significant.

Genetic and Phenotypic Correlations

An individual trait does not operate by itself. Usually there is some association between traits. These associations, measured with a correlation coefficient, are referred to as phenotypic correlations. The phenotypic correlation has both a genetic and an environmental contribution. Some genes affect more than one trait. When we refer to genetic correlations among traits we are referring to whether or not the same gene, of a number of genes that are responsible for inheritance, affect two or more economic traits. The genetic correlation evaluates common genetic contributions while the phenotypic correlation evaluates both the genetic and environmental effects.

Correlations between traits are important when considering multiple trait evaluation. Genetic correlations can help us evaluate such "indirect" effects of selection. These correlations are not always favorable. Unfavorable genetic correlations must be accounted for when selection criteria are defined. A favorable genetic correlation might allow us to make selections more efficiently. Genetic correlations can be estimated by selection for one trait over a period of time and noting whether or not there is a change or correlated response in traits not selected for. We must be careful when doing single trait selection because there could be unfavorable changes in other traits.

Pleiotropy plays a large role in the cause of genetic correlations between traits (Lasley, 1987). Pleiotropy is the process whereby one gene may affect two or more traits. Linkage also may be another factor that contributes to genetic correlations between traits. Linkage means that genes are carried on the same chromosome and some genes may be so closely linked together on the same chromosome that they seldom, if ever separate by crossing over during synapsis in meiosis. Genes that are closely linked on the chromosome would tend to stay together over several generations and the association of the traits determined by them would persist. Genes that are located farther apart on the same chromosome would stand a better chance of separating during crossing over in meiosis.

If we select for one trait and do not change another we might say that the two traits are inherited independently. If this is the case we must select for both traits at the same time in order to make improvements in both traits.

Selection for Quantitative Traits

Quantitative traits are those traits that are affected simultaneously by many pairs of genes and the environment. These traits are controlled by additive and non-additive gene action. When selecting for quantitative traits, the breeder attempts to estimate the genotype of the individual from its phenotype. No quantitative trait is 100 percent heritable because the environment and nonadditive gene action always affect the phenotype to a certain extent. It is very important when selecting animals from a herd or population that these animals be evaluated within the same contemporary group.

Multiple Trait Selection

Efficiency of livestock production is seldom determined by selecting for just one trait. If there are several objectives there should be multiple criteria for selection. Any trait that has an economic value should be considered. Some traits may be left out because they have a low heritability. The final criterion should include those traits that provide the maximum improvement in overall genetic merit.

The decision to include a trait in a selection program depends on several different factors. The heritability of the traits is an important consideration. Traits with low heritabilities should not be included in the selection criterion unless they are quite important economically. Several reproductive traits have very low heritabilities but reproduction is very important to overall efficiency and is quite variable. Another factor is the economic importance of a trait. Only traits with economic importance should be included when making selection decisions.

The relationship with other traits is also important. Genetic correlations provide us with a measurement of relationships between traits. If two traits have a strong genetic correlation it means that selection for one will lead to changes in the other. If this correlation is favorable it may mean that only one of the two traits needs to be considered for the final criterion.

The most efficient method for improving several traits at a time is the index selection. The selection index takes into account heritabilities, genetic and phenotypic correlations, standard deviations and economic values for all the traits which contribute to overall efficiency. In reality we are improving the economic merit for that animal. The index method of selection involves the separate determination of the index weighting for each of the traits selected for. The values for each component of the selection index are added together to come up with an overall value for that animal. The animals with the highest total scores are then kept for breeding purposes (Lush, 1945).

Selection for Lean Gain and Lean Gain Feed Conversion

The market hog in today's market place is a product of selection for increased leanness by swine breeders to reduce feed costs and enhance consumer acceptance. Genetic correlations indicate that leaner animals have an increased percentage of lean cuts, more loin eye and less backfat (Stouffer and Burgart, 1965; Topel et al., 1965 Cross et al., 1970; Adams et al., 1972.; Hertzer and Miller, 1973). Selection for increased growth has been effective in pigs (Craig et al., 1956; Rahnfeld and Garnett, 1976; Fredeen and Mikami, 1986a; Kuhlers and Jungst, 1990, 1991 a, b). Usually, however, just direct selection for ADG results in animals that are much fatter.

The swine industry today is concerned with doing an efficient job of converting dietary energy into carcass lean as more and more pressure is put on the producer by consumers demanding a leaner product. This pressure eventually makes its way to the packer and this is where this pressure will directly affect the producer. Davies and Lucas (1972 a, b) suggested that selection solely for ADG in pigs results in a decrease in feed efficiency at high food intake levels and that pigs need to be selected which are efficient on higher food intakes. However studies of selection for growth rate in mice by Falconer and Latyszewski (1952) and in swine by Fowler and Ensminger (1960) do not agree with this idea. We must consider how an animal utilizes the feed it consumes. First the animal has to meet the requirements of existing tissues and of course, the muscle tissues have greater daily requirements than fat for maintenance. Bichard (1978) suggested that if an animal has had sufficient protein and energy intake to maintain itself and to grow essential tissues at the most rapid rate at which it is genetically capable it shunts any surplus food into fat depots.

Feed accounts for 60 to 80 percent of the cost of production in most systems (Bichard 1978). So really the most important index of efficiency is feed consumed per unit of lean produced which is more commonly called lean tissue feed conversion. Bichard (1978) suggested that there are various factors that affect lean tissue feed efficiency. Some of these factors are target fat, intake, lean tissue growth rate, maintenance cost of tissue synthesis, efficiency of digestion and proportion of inedible parts in the body. Target fat is the insurance energy which the animal prefers to lay down when it is accreting protein. An animal which deposits less variable fat is also going to have an improved feed efficiency value, particularly if it has achieved that by a lower intake.

Another point related to lean tissue feed efficiency is that for a given feed intake the animal which has a higher rate of lean tissue gain is going to use more of available feed to build into lean and have less of it left over which has to be put into costly variable fat. So lean growth is a key variable when improving lean tissue feed efficiency.

Bichard (1978) suggested that when selecting for lean tissue feed efficiency, the feeding conditions under which selection takes place must be determined. In North America, the more common method of feeding has been the ad libitum system. It would be of interest if lines could be identified which are more efficient at higher intakes. If selection programs are to be designed to develop these lines, it is important first to determine the best feeding regimen for performance testing. Hammond (1947) stated that selection should be under conditions in which the animal has the greatest potential for expression of that trait; then under full feeding this is likely to occur.

However, results from some studies involving selection for growth rate in mice (Falconer and Latyszewski, 1952) and in pigs (Fowler and Ensminger, 1960) do not agree with the theory of Hammonds. Improvement in the ad libitum lines was mostly due to an increase in the rate of food intake whereas in the restricted lines the improvement was through increase in the efficiency of use of each unit of food consumed. Fowler et al. (1976) discussed different ways of selecting pigs under different feeding programs. The programs they described were a modification of the one proposed by Kielanowski (1968). Pigs are selected for lean tissue growth rate estimated at the end of a performance test of set duration and food intake. The animals that would be expected to be selected under these conditions would be ones that grew quickly because they were able to partition energy toward lean and away from fat deposition with lean having a lower energy cost than fat (Webster 1977). There are various sources of evidence in the literature that seem to support this claim (Falconer and Latyszewski, 1952; Fowler and Ensminger, 1960; Hetzel and Nicholas 1986; and McPhee and Trappett, 1987). However, direct selection for food conversion ratios have been somewhat unsatisfactory in that little change has been made (Dickerson and Grimes, 1947; Jungst et al., 1981). Pym and Nichols (1979) found that food conversion ratios in chickens can be improved by direct selection. Pym and Solvyns (1979) also found that direct selection for improved food conversion improved the carcass lean to fat ratio.

Index selection has been effective in improving gain and decreasing fat (Sather and Fredeen, 1978; Vangen, 1979, 1980). Leymaster et al. (1979 a, b) also were interested in studying the direct response of selection for two indices of leanness, one for weight of lean cuts at a constant age and another for percentage lean cuts at 180 lb. Response in percentage of lean cuts was .63 and .11% per generation for each of the lines, respectively.

Although selection for lean gain through index selection has been an effective means of selection, there have been tendencies to drive down feed intake when selecting for efficient lean gain (Smith et al., 1991). Fowler et al. (1976) also predicted that the improvements in efficiency and backfat would be the result of decreased intake. So the question is raised can we do a better job of selecting for lean tissue feed conversion by the economic selection method or can we do a better job of selecting for lean tissue conversion through a biological index which selects for the selection objective in a direct manner rather than using the component traits in an index. The biological method of selection has certain advantages. One advantage to this method of index selection is that it eliminates the need for parameter estimates and economic values that are required to derive an economic index. Another advantage would be selection for lean tissue feed conversion without sacrificing a decrease in intake.

Economic indexes have been criticized for several reasons. Some suggest that selection indices do not detect small changes in economic weights and genetic parameters (Fowler et al., 1976; Vandepitte and Hazel, 1977; Smith, 1983; Simm et al., 1985). A more detailed explanation of the negative points concerning index selection follows: (1) the economic relativities may not remain stable; (2) the choice of weightings of objectives may relate only to a restricted set of conditions; (3) the value of a unit increase in a desirable character may not be linear; (4) genetic and phenotypic parameters may vary with the conditions of testing such as breed and strain (Fowler et al., 1976).

Index Selection for Growth

Selection for quantitative traits such as lean tissue growth and lean tissue food conversion is further complicated because some of the measurements cannot be measured directly in the live animal (Simm et al., 1987). However indirect selection for these traits by selection on component traits such as increased ADG and decreased backfat can be accomplished. A large number of studies have reported the results of selection using an index that included two or three traits. Response to selection on an index of gain and backfat was reported in a number of studies (Vangen, 1974; Sather and Fredeen, 1978; Ollivier, 1980; Cleveland et al., 1983; McKay, 1990).

Vangen (1974) selected on divergent phenotypic indexes. An upward index selected for increased gain and decreased backfat while a downward index selected for decreased gain and increased backfat. The phenotypic index was intended to weight the traits equally based on their phenotypic standard deviations. Efficiency was improved and growth rate increased in the upward line. In the downward line response was unfavorable for both traits.

Sather and Fredeen (1978) constructed a similar phenotypic index of gain and backfat that resulted in improvements in both index traits. Response per selection in the index line was .30 and .25 for gain and backfat, respectively (Fredeen and Mikami, 1986). Total intake from 56 d to 90 kg was decreased, thus the improvement in growth rate was a result of improved efficiency. However there were no differences between lines for average daily intake.

Another study that selected for a phenotypic index of gain and backfat was conducted by McKay (1990). Once again in this study both traits were standardized by their estimated phenotypic standard deviations. Response per generation for backfat was -.70 and -.35 for a Yorkshire and Hampshire line, respectively. Response per generation for daily gain was essentially zero. This indicates that in this index very little selection pressure was put on daily gain.

Cleveland et al. (1983) selected for gain and backfat in an economic index. This index weighted daily gain more than backfat in terms of phenotypic standard deviation units. Backfat was decreased by 5.4% and daily gain increased by 12.5% after five generations of selection. Barrows from the index and control lines were individually fed starting at 25 kg for a constant time period. These pigs were tested on rations with three different levels of intake. These intake levels consisted of ad libitum, 91% of predicted ad libitum or 82% of predicted ad libitum (Cleveland et al., 1983). Lean gain was greater in the index line by 70 g/d at the two highest feeding levels. Lean growth was decreased the most in the index line when restricted to the 82% level as compared to ad libitum. Lean growth at the 82% intake level may have been posing a restriction in the daily amount of protein that is available for lean growth.

McPhee (1981) defined lean tissue feed conversion as the breeding objective in an index that included increased growth rate, improved feed conversion ratio (feed/gain) and decreased backfat. Pigs were evaluated from 45 to 80 kg under a semi-ad libitum feeding program. These pigs were allowed to consume ad libitum for 20 minutes twice a day. Response to selection was evaluated in two feeding trials when selection was terminated after 4.3 generations of selection. The index line gained faster when fed a limited ration, but the control line gained faster when fed ad libitum. The decreased growth for the select line can be attributed to a lower voluntary food intake; but the index line was more efficient and had about 12% less backfat. Selection using this index improved lean tissue feed conversion by 7.5% at ad libitum intake and 5.8% at the restricted feeding level. Lean growth rate was improved by about 5% under limited intake, but at ad libitum intake the index line had only a 1.5% advantage in lean growth. Selection had its effect primarily by decreasing intake, and to a lesser extent by increasing lean growth rate.

In the five studies involving index selection for increased growth rate and decreased backfat, lean growth rate and the efficiency of lean growth improved as the result of index selection for the two traits. In two of the studies intake decreased but gain remained the same resulting in an improvement of lean growth efficiency, but little change in actual growth rate. Actual amounts of response to each index varied. The amount of response for the component traits in each study varied. This response varied due to the weightings given to the component traits. These weightings may have differed due to some indexes were phenotypic indexes and other were economic indexes. If economic indexes are used then the weightings of each trait will be affected by the relative economic values placed on each trait.

Selection for Growth Under Limited Intake

Fowler et al. (1976) suggested that direct selection for the product traits lean growth rate and lean feed conversion efficiency may overcome some of the problems associated with economic selection indices. Fowler et al. (1976) proposed that one way to select for lean tissue feed conversion would be to select for ADG under scaled feeding condition in order to remove variation in intake. This method of selection should identify those animals that do the most effective job of converting energy into lean rather than fat.

Two mouse studies tend to agree with this idea. Hetzel and Nichols (1986) selected two lines for high 3 to 6 week growth, one on restricted and the other on ad libitum intake. In an evaluation of lines at both feeding levels, the mice that gained the fastest on any one feeding level were the ones that were selected for on that level. However, the line selected on restricted feeding had a greater ratio of lean to fat gain overall than the one selected on ad libitum intake.

McPhee et al. (1980) selected mice for 5 to 9 week gain on a set feeding ration. However, when these mice were evaluated at the set scale and ad libitum intake it was found that gains had been made in the rate and efficiency of growth at both levels of feeding. This study only consisted of a line of mice selected for gain at a set feeding scale, so appetite was not allowed to be expressed. The hypothesis for selection under this feeding regime was that "When animals are fed the same amount over the same period, selection for the fastest growers would result in partitioning of metabolizable energy toward more protein and less fat." McPhee (1986) attempted to add another dimension to his earlier research and included two selection lines. Lines of mice were selected for increased 3 to 6 wk growth under either an unrestricted nutritional environment (F) or one that was restricted to 83% of predicted ad libitum intake

(S). These mice after seven generations of selection were evaluated at both ad libitum intake and 83% of predicted ad libitum. Each line performed better under the diet which they were selected. The F line grew 19% faster and had a 9% advantage in total body efficiency than the S line on free feeding. The S line grew 15% faster and was 15% more efficient than the F line on set feeding. Compared to the unselected control line, food intake per day on free feeding was 4% higher in the F line and 6% lower in the S line. No differences were observed between lines in food intake per gram of body weight. Compared to the controls, the select lines contained more carcass protein. However, the ratio of lean to fat was highest in the S line under both feeding regimes. The authors concluded that if the breeding objective is lean tissue feed conversion, restricted feeding is the best nutritional environment for selection.

Kielanowski (1968) hypothesized the use of growth rate alone as the selection criteria with scale feeding should increase both the rate and lean content of growth. The elimination of variation in food intake during performance testing apparently succeeded in exposing to selection improved covariation between growth rate and fat. This is the consequence associated with partitioning of food energy between lean and fat deposition, the former having a lower energy cost than the latter.

Until the present time there have only been three studies to compare response to selection under different levels of intake in the pig (Fowler and Ensminger, 1960; McPhee et al., 1988; Cameron and Curran, 1994; Cameron et al., 1994). The study conducted by Fowler and Ensminger (1960) was designed to interpret genotype by environment interactions. High and low nutrition lines were selected on an index of gain and litter size. The low line received 70% of the intake level of the high line. When both lines were evaluated at ad libitum intake, the low line grew more rapidly in two of the three generations and was equal to the high line in the third generation.

The advantage of the high line in gain can be attributed to their potential intake capacity. Thus when these pigs were fed at the same level of intake the high line pigs were unable to compete. The authors in this study also suggested that the improved superiority in feed efficiency of the low line pigs could have been due to a lowered metabolic rate and/or repartitioning of growth from fat to lean.

McPhee et al. (1988) used ham lean as a predictor of lean content in the carcass of the pig. Ham lean could be viewed as a selection index aimed at increasing the rate and lean content of growth which are functions of growth rate and fat. Weight of ham lean was used as the selection criterion. This selection was practiced for 4.5 generations under a restricted intake level. Pigs were tested for 12 weeks starting at 25 kg. Pigs were limited to the same amount of food daily so that all pigs received the same amount of food over the 12 week period. The weight of ham lean was predicted from growth rate and ultrasonic fat depth.

Response was measured under a feeding regime of either ad libitum or the restricted ration under which they were selected. When evaluated at either intake level the select line grew faster, was leaner, had a higher weight of ham lean and had a lower feed:gain than the control when fed at either intake level. The select and the control line differed more at ad libitum for the above mentioned traits.

The authors in this study suggested that selection for lean under ad libitum intake, if practiced, may have been slower. This was based on a high genetic correlation between ad libitum and the restricted feeding levels by having similar realized responses, the higher heritability for ham weight under limited intake (.43 vs. .28) and a small, favorable correlation between growth and fat under limited intake.

Summary of Selection for Growth Under Limited Intake

Some of the earlier studies involving selection under restricted intake were interested in examining genotype by environment interactions. However in recent years, selection under restricted intake has been interested in removing intake variation, in an effort to reveal new variation in selection for lean gain and lean tissue feed efficiency.

Selection for lean gain and lean tissue feed efficiency in the pig has been primarily through selection of component traits (growth and backfat). Single trait selection has not been reported.

CHAPTER III

PROGENY RESPONSE IN LEAN TISSUE FEED CONVERSION TO SELECTION FOR POSTWEANING GAIN AMONG BOARS WITH LIMITED FEED INTAKE

Abstract

Seven generations of selection have been completed in sublines of a population previously selected for postweaning ADG among animals allowed ad libitum access to feed. Selection criteria in the present study were 1) postweaning ADG among boars allowed ad libitum feed intake (F), 2) postweaning ADG among boars limited to 83% of predicted ad libitum feed intake (L), and 3) a relaxed selection control. The working hypothesis was that selection for ADG at a standard, limited intake identifies those animals that partition the allotted energy to the relatively efficient deposition of lean tissue. To evaluate response to selection, approximately 24 barrows were sampled from each selection criterion and assigned either ad libitum access to feed or 83% of predicted ad libitum for the postweaning period from 36 to 105 kg. Carcass measurements of fat thickness were taken at 105 kg in the area of the first rib, last rib, last lumbar vertebra and the 10th rib. The right side of each carcass was separated into lean, fat and bone. ADG, average daily feed intake, feed

efficiency, percentage of lean, percentage of fat, lean tissue gain (LTG) and lean tissue feed conversion (LTFC) were evaluated at each feeding level for each line. At ad libitum intake F barrows gained more (P<.01) than C barrows and consumed more feed (P<.05). At both ad libitum and limited intake, L barrows were more (P<.05) efficient than C barrows. At both ad libitum and limited intake there was a tendency (P<.20) for L barrows to gain more than C barrows. At ad libitum intake, there were no differences (P>.20) between F or L barrows vs C barrows for any backfat depth however, at limited intake L barrows had significantly (P<.01) less average backfat and less fat at the first rib. Also at limited intake L barrows had less 10th rib fat and last rib fat. F barrows did not differ (P>.20) from C barrows for any backfat depth at limited intake. At ad libitum intake L barrows had smaller (P<.05) loin eye areas than C barrows and tended (P<.20) to have smaller loin eye areas at limited intake. There were no differences at either intake level for carcass length among any of the lines. At ad libitum intake F barrows had a lower (P<.05) percentage of lean and a higher (P<.05) percentage of fat and F barrows had a tendency (P<.20) to be lower in fat free lean. Also at ad libitum intake, L barrows had a tendency (P<.20) to have a lower lean percentage and a higher (P<.20) fat percentage as compared to C barrows. There were no differences (P>.20) between F and L barrows compared to C barrows for any of the carcass composition traits at limited intake with the exception of bone percentage. L barrows had a tendency (P<.20) to have a higher bone percentage. There were no differences in LTG and LTFC among lines of pigs in this evaluation. Present results do not indicate a clear advantage for selection under limited intake.

Introduction

In recent years consumers have become interested in decreasing their fat intake due to health related issues. The swine industry must make changes to meet these demands. Methods must be developed that identify those animals which most efficiently convert energy intake to lean rather than to fat.

Selection for increased weight at a standard age has shown positive results (Krider et al., 1946; Kuhlers and Jungst, 1990; Kuhlers and Jungst, 1991 a, b) and selection for ADG (Rahnfeld, 1971; Fredeen and Mikami, 1986b Woltmann et al., 1992) has been successful.

Response in a favorable direction has been reported in a number of index studies. An index containing only gain and backfat resulted in progress for both traits (Vangen, 1974; Sather and Fredeen, 1978; Ollivier, 1980; Cleveland et al., 1983; McKay, 1990). Metabolizable energy intake required per unit of edible lean was reduced by index selection (Cleveland et al., 1983). Selection using an index for increased gain and decreased backfat generally results in improvements of lean growth rate and efficiency of lean growth. McPhee (1981) and Henderson et al. (1982) reported that index selection that included gain, backfat and feed conversion resulted in improvements in efficiency and backfat but not growth rate. These improvements were made at the expense of decreasing intake.

Fowler et al. (1976) proposed a more direct method of selecting for lean tissue growth rate (LTGR) and lean tissue feed conversion (LTFC). Selection under an ad libitum environment for ADG may result in selecting those individuals that simply consume more food. Selection under conditions in which variation in feed consumption is removed should identify those animals that do the most efficient job of partitioning energy into lean rather than fat. This should happen because about three units of lean tissue can be produced at the same energetic cost as one unit of fat tissue (Fowler et al., 1976).

Heritability estimates for gain in mice for which lines had been developed under both an ad libitum environment and an environment in which intake variation had been removed, were similiar (McPhee et al., 1980; Hetzel and Nicholas, 1982; McPhee and Trappett, 1987).

In a study by McPhee and Trappett (1987), lines of mice were selected for increased growth either at ad libitum intake and in a restricted nutritional environment. When progeny from both lines were evaluated at ad libitum intake, progeny selected at at libitum intake grew faster, were more efficient, consumed more and partitioned more energy to fat. However when progeny from these two lines were evaluated in a restricted feeding environment, progeny from the restricted line grew faster and were more efficient.

McPhee et al. (1988) developed a line of pigs that was selected for increased ham weight under restricted feeding. When evaluated at either ad libitum intake or restricted intake the select pigs were faster growing, more efficient, leaner and had increased ham weights. This study however did not include a line that was selected under ad libitum intake. Thus no direct comparisons of single trait selection were made for average daily gain at ad libitum intake.

Beginning in 1985, lines were developed from a line that had been previously selected for average daily gain at ad libitum intake. The two selection lines that were intiated included selection for ADG at ad libitum intake and selection for ADG at limited intake (83% of predicted ad libitum intake). The line selected at limited intake was developed in an attempt to remove variation in intake. Also a relaxed selection line was included in this study. At the end of seven generations of selection, responses in LTGR and LTFC were evaluated at both ad libitum and limited feed intake.

Component traits of LTGR and LTFC such as daily gain, feed intake, and fat are hypothesized to differ depending on the intake level under which selection occurs. To test the above hypothesis the objectives of this study were to 1) quantify and compare responses in component traits of LTGR and LTFC to selection for gain under ad libitum intake or limited intake and 2) quantify and compare responses of LTGR and LTFC to selection for gain under ad libitum intake or selection for gain under limited intake.

Materials and Methods

Base Population Development

The original base population was developed at the Southwest Livestock and Forage Research Station located near El Reno, OK. Hampshire boars were purchased in pairs from central test stations in Iowa, Missouri, Nebraska and Oklahoma during the fall of 1979 and spring of 1980. Boars were selected on the index recommended by the National Swine Improvement Federation (Hubbard, 1981) that focused on ADG, decreased backfat and improved feed efficiency. Within each pair of boars, one boar had a value of at least 118 and the other had a value less than 90. The Hampshire boars were mated to three and four breed cross gilts consisting of Duroc, Spotted, Yorkshire and Landrace breeding. Development of these crossbred gilts was described by Buchanan and Johnson (1984) and McLaren et al. (1987 a, b). Offspring from these matings were born in the spring and fall of 1980.

The same selection criteria were used to purchase pairs of tested boars in the fall of 1980 and spring of 1981. Offspring that were sired by Hampshire boars were randomly mated to high and low indexing Duroc boars for production of progeny in the spring and fall of 1981. Litters born in 1981 were the base population for fast and slow growth lines.

Selection Lines

The base population for this study was developed from a line of pigs that had been previously selected for rapid growth from 9 weeks of age through 100 kg (F'). In 1985, F' was subdivided to intiate new selection lines.

Pigs born in the fall of 1985 and spring of 1986 represent the base generation for the fall farrowing group and spring farrowing group, respectively. The base population was composed of F' males and females. Males were randomly assigned to be allowed either ad libitum or limited intake (83% of predicted ad libitum). Each intake group was composed of 36 males per farrowing group tested from 36 to 104 kg. The six boars with the highest average daily gain under limited intake sired generation one of a line (L) in which selection was for increased ADG from 36 through 104 kg at limited intake. The six boars with the highest average daily gain at ad libitum intake sired generation one of a line (F) in which selection was for increased ADG at ad libitum intake. The F line was a continuation of F', except that the period under which selection occurred changed from 9 wk of age through 100 kg to 36 through 104 kg. Six average gaining boars from the ad libitum fed group sired generation one of an unselected control (C). Females were tested under ad libitum intake and average females from each litter were randomly assigned to either the C, F or L line. With these assignments of females to lines and selection of boars, the lines remained closed and selection continued within line.

Selection was practiced only on males from 36 kg through 104 kg. There was no intentional selection made among females in any of the lines. Replacement gilts within each line were chosen to represent the average gilt in each litter.

A total of seven generations of selection was practiced. Pigs born in the fall of 1992 and spring of 1993 represent the seventh generation of response. Boars and gilts were replaced after producing one litter, resulting in a generation interval of 1 yr. Each line was maintained with approximately six boars and 25 females. The replacements were selected from 36 males and 75 to 100 females were tested per line. One or two males per litter were randomly chosen at 21 days of age to be tested. The remaining males were castrated.

Boars from the C and F lines were penned by line at 8 or 9 weeks of age; individuals began the test when they reached an on-test weight of 36 kg. Boars from L were placed in individual pens when they reached a weight of 31 kg. By putting the boars in individual pens at an earlier weight than the on-test weight, an approximate one week adjustment period was allowed.

Boars from L were individually fed 83% of predicted ad libitum intake. Predicted ad libitum feed intake for each boar was based on feeding trails with barrows from the F' line (Woltmann et al., 1992). L boars were put on a feed restriction at the beginning of on-test. All boars were fed a corn-soy diet that was approximately 62% lysine and about 14.5% crude protein.

In each generation, 36 L boars were evaluated, each in an individual pen . These boars were weighed weekly so individual intake levels could be adjusted based on each boar's individual weight. Average daily gain was measured through the first week a particular boar reached 104 kg or greater. Usually eight to ten of the fastest gaining boars were kept each generation within each farrowing group. The six fastest gaining boars were selected to produce offspring in the next generation. However, occasionally spare boars had to be used if one of six fastest gaining boars failed to breed gilts.

In all generations past the base generation, 36 C and F were tested each generation in groups of 12 and received ad libitum access to feed. Average daily gain was measured over the same weight range. All boars in each pen were weighed weekly until they reached an on test weight of 36 kg. Boars were individually removed from test when they reached 104 kg. In F, the six fastest gaining boars were chosen to produce offspring in the next generation. In the C line the six middle ranking boars for ADG were selected to produce offspring in the next generation.

The growing-finishing barrows and gilts were housed in two barns located adjacent to each other. All boars were tested in the same barn. Most of the barrows and gilts were housed in one barn however there were a few pens in the same barn as the boars. Barrows and gilts were penned together by line in pens containing 16 to 18 pigs. Pigs that were littermates were penned together whenever possible. The barns consisted of solid concrete flooring with a narrow flush gutter. Environmental control inside the barns consisted of modified sides that could be opened during warm weather, a mist system that allowed for evaporative cooling and heaters. Pigs were moved from the nursery into the growing finishing barns at eight weeks of age. Barrows and gilts were allowed a one week adjustment period prior to beginning test at nine weeks of age.

Barrows and gilts were put on a finishing diet when the pen average weight was 54 kg. Grower diets were balanced to .75% lysine (about 15.5% crude protein) and finishing phase diets were balanced to .62% lysine (about

14.5% crude protein). The barrows and gilts have been used to conduct various nutritional trails. The experimental diets may have varied slightly from the lysine and crude protein levels described previously, depending on the nature of the nutritional treatment. All diets were assigned in a factorial arrangement with lines.

After a pig in a given pen reached 100 kg, all individuals in that pen were weighed weekly. Individual pigs were removed from test the first week that they weighed at least 100 kg.

Two females from each litter were chosen as replacements the first week any gilt from the litter reached 100 kg. At this time the gilts within a litter were ranked based on weight and the two middle ranking gilts were kept as replacements. If an odd number of gilts occurred in a litter, the middle ranking gilt and the one that was nearest the middle gilt were kept.

The present evaluation of F, L, and C barrows consisted of a 3 x 2 factorial arrangement in which each line was evaluated at ad libitum intake or limited intake (83% of predicted ad libitum intake).

A total of 72 barrows was used in this analysis. Barrows were sampled from the fall (n=36) and spring (n=36) farrowing groups. Within each farrowing group, 12 barrows from each line representing all sires within the line were individually fed at ad libitum intake or limited intake.

Two barrows were sampled from each of 36 litters. One barrow was designated to be put on test, the remaining barrow was slaughtered at 36 kg and the right side of each carcass dissected into lean, fat, and bone. Barrows were either put on test or slaughtered the first week they reached 36 kg. The barrow that was slaughtered was used in the development of prediction equations. Separate equations were developed to predict on test lean and fat free lean. Ultrasonic backfat measurements, loin eye area and weight of the slaughter barrow served as predictor or independent variable in the prediction equations developed. The remaining littermate barrow was evaluated for ADG, average daily feed intake, feed efficiency, LTG and LTFC from 36 to 104 kg.

Carcass data from both the slaughter barrow and the barrow designated to go on test included slaughter weight, carcass length, backfat thickness, loin eye area and right-side carcass weight. The right side of each carcass was divided into the major wholesale cuts of the ham, loin, shoulder, and belly. The lean from these cuts was combined and ground, and three 110-g samples were taken for proximate analysis. Lean samples were powdered with liquid nitrogen. Two 2 g subsamples were weighed and put into Waltmann 41 15cm ashless filter paper. Each sample was dried and reweighed for moisture determination. The samples were put into ether for fat determination of lean.

Selection Differentials

Selection differentials for ADG were calculated by deviating each selected individual's record from the appropriate generation-farrowing group-line-sex subclass mean. Unweighted selection differentials for each individual were proportionately weighted by the number of progeny that had an ADG record to calculate weighted selection differentials. Standardized weighted selection differentials were calculated by taking the weighted selection differentials and dividing them by the within line SD for ADG. All cumulative selection differentials were calculated by adding the selection differential from one generation back to the previous generation. Boar and gilt differentials were calculated separately.

Statistical Analysis

Traits analyzed included ADG, average daily feed intake (ADFI), feed efficiency (FE) and feed conversion (FC). Also a number of traits associated with lean growth were evaluated: lean tissue gain per day (LTG), fat free lean tissue gain per day (FFLTG), lean tissue feed conversion (LTFC), fat free lean tissue feed conversion (FFLTFC), lean tissue gain expressed as percentage of ADG (LNGA%) and fat free lean tissue growth expressed as a percentage of ADG (FFLNGA%). Carcass traits that were evaluated included carcass first rib fat depth (CFRB), carcass 10th rib fat depth (C10th), carcass last rib fat depth (CLRB), carcass last lumbar vertebra fat depth (CLLV), carcass average fat depth (CAFD), carcass loin eye area (CLEA) and carcass length (CL). Several traits associated with tissue composition in the carcass were evaluated: total lean (LEAN), total fat free lean (FFLEAN), total fat (FAT), total bone (BONE), LEAN/carcass weight x 100 (LEAN%), FFLEAN/carcass weight x 100 (FFLEAN%), FAT/carcass weight x 100 (FAT%), BONE/carcass weight x 100 (BONE%).

A number of statistical models were used to analyze the traits of interest. Refer to appendix Tables 11 through 14. The effects of line, diet and farrowing season were cross-classified variables when included in the model. Also weight, $(weight)^2$ and the interactions of these two covariates with line, diet and farrowing season were included in the full model. The General Linear Models procedure in SAS (1985) was used. A full model was analyzed for each trait, but the final model or reduced model included only sources of variation that were considered statistically significant. All main effects and their interaction effects were kept in the final or reduced model. All non-significant interactions (P>.20) that were associated with the covariates were removed from the final model.

Least squares means for each of the two selection lines (F and L) were compared to the control line (C) using Dunnett's t-test. In the presence of a significant line x feeding level interaction, these same comparisons among lines were made at each feeding level.

Prediction of on-test lean was accomplished by using forward regression procedures. Dissected lean weights for barrows slaughtered at 36 kg were regressed on weight, weight^2, ultrasonic measures of backfat depth and loin eye area. Sources of variation included in the final model for prediction of on test lean included weight, ultrasonic measures of loin eye area and first rib backfat depth.

Results and Discussion

Selection Differentials

Selection was practiced only in F and L boars. Unweighted deviations for males and females are presented in Tables 1 and 2 for the fall and spring farrowing groups, respectively. Weighted deviations for males and females are presented in Tables 3 and 4 for the fall and spring farrowing groups, respectively. Each deviation or individual selection differential was weighted by the number of offspring produced by that boar or gilt that had a daily gain record the following generation. Weighted and unweighted were numerically similiar for all generation farrowing group-line subclasses. For the fall farrowing group, the ratio of weighted vs unweighted selection differentials was essentially 1 or greater for males. For females within the fall farrowing group the ratio of weighted vs unweighted selection differentials were essentially 1 or greater. In the spring farrowing group, ratios of weighted selection differentials to unweighted selection differentials for males were essentially 1 or greater in all generations with the exception of generation 0 in C, generations 1 and 6 in F, and generations 1 and 4 in L.

Total unintentional selection in the gilts was essentially zero (Table 4) for the F line in the spring farrowing group and was 5% of the males cumulative selection differential in the fall group. In the L line unintentional selection was about 10% of the selection differentials for males (Table 4). Because L boars received different amounts of feed than L gilts, the measured unintentional selection cannot be assumed to be a direct function of the standard limited intake with which the males were selected. Weighted differentials in males were at least twice as high in F, as compared to L (Tables 3 and 4). However, the phenotypic SD for ADG under ad libitum intake was about twice as large as the SD under limited intake. When standardized, the relative amount of total selection realized was similar across line and farrowing group (Tables 5 and 6). The standardized male weighted cumulative selection differentials for F were 9.4 and 8.2 for fall and spring farrowing group, respectively. The standardized male weighted selection differential for L were 7.4 and 8.6 for fall and spring, respectively (Tables 5 and 6).

Similiar differences in variation due to feeding levels have been reported in mice. Woltmann (1992) cited that (Hetzel and Nicholas, 1982) reported that the phenotypic variation for weight gain was 2.5 times higher in a line selected under ad libitum intake as compared to a line selected under ad libitum intake as compared to a line selected under restricted intake. McPhee and Trappett (1987) reported in mice that the cumulative selection differntial for gain was 50% higher in a line selected under ad libitum intake versus a line that had been selected for daily gain under restricted feeding.

Growth Traits

Least squares means for growth traits are presented in Table 7. When allowed ad libitum feed intake, F barrows had greater (P<.01) ADG and consumed more (P<.05) feed per day than C barrows. Also at ad libitum intake, L barrows had a tendency to gain faster (P<.20) than C barrows, but had similar daily feed intake. At ad libitum intake L barrows were more (P<.05) efficient than C barrows. L barrows also had better (P<.05) feed conversions than C barrows. Woltmann et al. (1993) also reported that F barrows and gilts at generation five had higher ADG and consumed more feed per day at ad libitum intake than L or C barrows and gilts. Although there were no significant differences in daily intake between barrows and gilts from L and C, but barrows and gilts from L did rank lower for daily intake at generation five.

At limited intake L barrows were more (P<.05) efficient and had higher (P<.05) feed conversion ratios than C barrows. Also there was a tendency (P<.20) for L barrows to gain more than C barrows. At limited intake F barrows did not differ from C barrows for ADG or ADFI.

McPhee and Trappett (1987) reported that in lines of mice that had been selected for increased 3 to 6 wk growth under a restricted (80% of predicted ad libitum intake) nutritional environment had higher ADG when evaluated at restricted as compared to a line that had been selected for increased 3 to 6 wk growth under an unrestricted nutritional environment. In another study using mice (Hetzel and Nicholas, 1986) that was similar to McPhee and Trappett (1987), two lines were selected for increased growth under both an unrestricted and a restricted nutritional environment. When both lines were fed at the same intake level, the restricted line gained the fastest and thus was the most efficient.

Only two studies in the pig have been designed to compare response to selection at both ad libitum intake and limited intake (Fowler and Ensminger, 1960; McPhee et al., 1988). Fowler and Ensminger (1960) reported on lines that had been selected on an index of gain and litter size. Selection occurred in a high and low (intake 70% of high) nutritional environment. At the high nutritional level , the low nutrition line grew more rapidly in 2 out of 3 generations that were selected. When both lines were fed the restricted ration performance of the low line was superior to the high in each generation. Vandergrift et al. (1985) also found that barrows at ad libitum intake had higher ADG than barrows that were limit fed. Barrows at limited intake were more efficient than barrows at ad libitum intake. Vandergrift et al. (1985) found no differences in efficiency between barrows that were allowed ad libitum intake or limit fed.

TABLE 1

UNWEIGHTED CUMULATIVE SELECTION DIFFERENTIALS (ADG,Kg) FOR FALL[a] FARROWING GROUP BY LINE

LINE[b]	GEN[c]	UNWEIGHTED DEVIATION FEMALE	UNWEIGHTED DEVIATION MALE	CUMULATIVE SELECTION DIFFERENTIAL FEMALE	CUMULATIVE SELECTION DIFFERENTIAL MALE
C	0	0.012	-0.020	0.012	-0.020
	1	0.023	-0.005	0.035	-0.025
	2	0.031	0.025	0.066	0.000
	3	0.032	0.006	0.098	0.006
	4	0.001	-0.009	0.099	-0.003
	5	0.023	0.000	0.122	-0.003
	6	0.054	-0.003	0.176	-0.006
F	0	0.021	0.101	0.021	0.101
	1	0.016	0.145	0.037	0.246
	2	0.033	0.127	0.070	0.373
	3	0.016	0.133	0.086	0.506
	4	-0.009	0.127	0.077	0.633
	5	-0.002	0.104	0.075	0.737
	6	-0.008	0.057	0.067	0.794
L	0	0.020	0.036	0.020	0.036
	1	0.010	0.062	0.030	0.098
	2	0.016	0.050	0.046	0.148
	3	0.007	0.054	0.053	0.202
	4	0.012	0.052	0.065	0.254
	5	0.026	0.040	0.091	0.294
	6	-0.003	0.038	0.088	0.332

[a]Fall group farrowed from mid-September through October.

[b]C=unselected control, F=selected for rapid growth at ad libitum intake, L=selected for rapid growth at restricted intake.

[c]Generation represents the amount of selection that occurred in the sow.

TABLE 2

UNWEIGHTED CUMULATIVE SELECTION DIFFERENTIALS (ADG, Kg) FOR SPRING[a] FARROWING GROUP BY LINE

LINE[b]	GEN[c]	UNWEIGHTED DEVIATION FEMALE	UNWEIGHTED DEVIATION MALE	CUMULATIVE SELECTION DIFFERENTIAL FEMALE	CUMULATIVE SELECTION DIFFERENTIAL MALE
C	0	0.012	0.018	0.012	0.018
	1	0.003	0.014	0.015	0.032
	2	0.018	0.004	0.033	0.036
	3	0.006	0.022	0.039	0.058
	4	0.002	0.046	0.041	0.104
	5	0.023	0.021	0.064	0.125
	6	0.004	0.000	0.068	0.125
F	0	0.029	0.153	0.029	0.153
	1	0.026	0.130	0.055	0.283
	2	0.011	0.110	0.066	0.393
	3	0.012	0.137	0.078	0.530
	4	0.008	0.142	0.086	0.670
	5	0.036	0.128	0.122	0.798
	6	-0.004	0.121	0.118	0.919
L	0	0.039	0.036	0.039	0.036
	1	0.000	0.073	0.039	0.109
	2	0.038	0.058	0.077	0.167
	3	0.009	0.059	0.086	0.226
	4	0.000	0.058	0.086	0.284
	5	-0.014	0.063	0.072	0.347
	6	0.024	0.056	0.096	0.403

[a]Spring group farrowed from mid-March through April.
[b]C=unselected control, F=selected for rapid growth at ad libitum intake, L=selected for rapid growth at restricted intake.
[c]Generation represents the amount of selection that occurred in the sow.

TABLE 3

WEIGHTED CUMULATIVE SELECTION DIFFERENTIALS (ADG, Kg) FOR FALL[a] FARROWING GROUP BY LINE

LINE[b]	GEN[c]	WEIGHTED DEVIATION FEMALE	WEIGHTED DEVIATION MALE	CUMULATIVE SELECTION DIFFERENTIAL FEMALE	CUMULATIVE SELECTION DIFFERENTIAL MALE
C	0	0.018	-0.021	0.018	-0.021
	1	0.052	-0.008	0.070	-0.029
	2	0.054	0.025	0.124	-0.004
	3	0.035	0.007	0.159	0.003
	4	-0.004	-0.004	0.155	-0.001
	5	0.034	-0.001	0.189	-0.002
	6	0.050	-0.003	0.239	-0.005
F	0	0.028	0.107	0.028	0.107
	1	0.020	0.143	0.048	0.250
	2	0.036	0.125	0.084	0.375
	3	0.020	0.131	0.104	0.506
	4	-0.047	0.128	0.057	0.634
	5	-0.006	0.103	0.051	0.737
	6	-0.008	0.066	0.043	0.803
L	0	0.009	0.036	0.009	0.036
	1	-0.054	0.064	-0.045	0.100
	2	0.044	0.052	-0.001	0.152
	3	0.008	0.055	0.007	0.207
	4	0.047	0.052	0.054	0.259
	5	0.092	0.046	0.146	0.305
	6	0.010	0.041	0.156	0.346

[a]Fall group farrowed from mid-September through October.
[b]C=unselected control, F=selected for rapid growth at ad libitum intake, L=selected for rapid growth at restricted intake.
[c]Generation represents the amount of selection that occurred in the sow.

TABLE 4

WEIGHTED CUMULATIVE SELECTION DIFFERENTIALS (ADG, Kg) FOR SPRING[a] FARROWING GROUP BY LINE

LINE[b]	GEN[c]	WEIGHTED DEVIATION FEMALE	WEIGHTED DEVIATION MALE	CUMULATIVE SELECTION DIFFERENTIAL FEMALE	CUMULATIVE SELECTION DIFFERENTIAL MALE
C	0	0.010	0.006	0.010	0.006
	1	-0.010	0.013	0.000	0.019
	2	0.082	0.003	0.082	0.022
	3	0.039	0.022	0.121	0.044
	4	-0.002	0.050	0.119	0.094
	5	0.022	0.021	0.141	0.115
	6	-0.021	0.003	0.120	0.118
F	0	0.030	0.158	0.030	0.158
	1	0.024	0.121	0.054	0.279
	2	-0.048	0.108	0.006	0.387
	3	0.006	0.137	0.012	0.524
	4	0.006	0.153	0.018	0.677
	5	0.036	0.126	0.054	0.803
	6	-0.054	0.114	0.000	0.917
L	0	0.044	0.037	0.044	0.037
	1	-0.004	0.069	0.040	0.106
	2	-0.011	0.061	0.029	0.167
	3	-0.021	0.064	0.008	0.231
	4	-0.016	0.054	-0.008	0.285
	5	-0.019	0.063	-0.027	0.348
	6	0.066	0.056	0.039	0.404

[a]Spring group farrowed from mid-March through April.
[b]C=unselected control, F=selected for rapid growth at ad libitum intake, L=selected for rapid growth at restricted intake.
[c]Generation represents the amount of selection that occurred in the sow.

TABLE 5

STANDARDIZED[a] WEIGHTED CUMULATIVE SELECTION DIFFERENTIALS (ADG, Kg) FOR FALL[b] FARROWING GROUP BY LINE

LINE[c]	GEN[d]	STANDARDIZED WEIGHTED DEVIATION FEMALE	STANDARDIZED WEIGHTED DEVIATION MALE	STANDARDIZED CUMULATIVE DIFFERENTIAL FEMALE	STANDARDIZED CUMULATIVE DIFFERENTIAL MALE
C	0	0.184	-0.214	0.184	-0.214
	1	0.531	-0.082	0.715	-0.296
	2	0.551	0.255	1.102	-0.041
	3	0.357	0.071	1.459	-0.030
	4	-0.041	-0.041	1.418	-0.011
	5	0.347	-0.010	1.765	-0.021
	6	0.510	-0.031	2.275	-0.052
F	0	0.286	1.092	0.286	1.092
	1	0.204	1.469	0.490	2.561
	2	0.367	1.276	0.857	3.837
	3	0.204	1.337	1.061	5.174
	4	-0.480	1.306	0.581	6.480
	5	-0.061	1.050	0.520	7.530
	6	-0.082	0.673	0.438	8.203
L	0	0.092	0.766	0.092	0.766
	1	-0.551	1.362	-0.459	2.128
	2	0.449	1.106	-0.010	3.234
	3	0.082	1.170	0.072	4.404
	4	0.480	1.106	0.552	5.510
	5	0.939	0.979	1.491	6.489
	6	0.102	0.872	1.593	7.361

[a]Standardized by the within line phenotypic standard deviation of .047 for L boars and .098 for C and F boars and all gilts.
[b]Fall group farrowed from mid-September through October.
[c]C=unselected control, F=selected for rapid growth at ad libitum intake, L=selected for rapid growth at restricted intake.
[d]Generation represents the amount of selection that occurred in the sow.

TABLE 6

STANDARDIZED[a] WEIGHTED CUMULATIVE SELECTION DIFFERENTIALS (ADG,Kg) FOR SPRING[b] FARROWING GROUP BY LINE

LINE[c]	GEN[d]	STANDARDIZED WEIGHTED DEVIATION FEMALE	STANDARDIZED WEIGHTED DEVIATION MALE	STANDARDIZED CUMULATIVE DIFFERENTIAL FEMALE	STANDARDIZED CUMULATIVE DIFFERENTIAL MALE
C	0	0.102	0.061	0.102	0.061
	1	-0.102	0.133	0.000	0.194
	2	0.837	0.031	0.837	0.225
	3	0.398	0.224	1.235	0.449
	4	-0.020	0.510	1.215	0.959
	5	0.224	0.214	1.439	1.173
	6	-0.214	0.031	1.225	1.761
F	0	0.306	1.612	0.306	1.612
	1	0.245	1.235	0.551	2.847
	2	-0.490	1.102	0.061	3.949
	3	0.061	1.398	0.122	5.347
	4	0.061	1.561	0.183	6.908
	5	0.367	1.286	0.550	8.194
	6	-0.551	1.163	-0.001	9.357
L	0	0.449	0.787	0.449	0.787
	1	-0.041	1.468	0.408	2.255
	2	-0.112	1.298	0.296	3.553
	3	-0.214	1.362	0.082	4.915
	4	-0.163	1.149	-0.081	6.064
	5	-0.194	1.340	-0.275	7.404
	6	0.673	1.191	-0.398	8.595

[a]Standardized by the within line phenotypic standard deviation of .047 for L boars and .098 for C and F boars and all gilts.
[b]Spring group farrowed from mid-March through April.
[c]C=unselected control, F=selected for rapid growth at ad libitum intake, L=selected for rapid growth at restricted intake.
[d]Generation represents the amount of selection that occurred in the sow.

TABLE 7

LEAST SQUARES MEANS FOR GROWTH TRAITS FROM BARROWS REPRESENTING FAST (F), LIMIT (L) AND CONTROL (C) LINES AND ALLOWED AD LIBITUM OR LIMITED FEED INTAKE.

	AD LIBITUM			CONTRAST[b]		LIMITED			CONTRAST[b]	
TRAIT[a]	F	L	C	F vs C	L vs C	F	L	C	F vs C	L vs C
ADG, kg	1.04	1.01	.95	**	+	.81	.85	.80	NS	+
ADFI, kg	3.44	3.28	3.23	*	NS	2.61	2.62	2.61	NS	NS
FE, feed/gain	3.30	3.25	3.44	NS	*	3.23	3.10	3.29	NS	*
FC, gain/feed	.30	.31	.29	NS	*	.31	.32	.30	NS	*

[a]ADG = Average daily gain; ADFI = Average daily feed intake; FE = Feed efficiency; FC = Feed conversion;
[b]NS = not significant at P>.20; + = significant at P<.20; * = significant at P<.05; ** = significant at P<.01.

Carcass traits

Least squares means for carcass characteristics are presented in Table 8. There was a tendency (P<.10) for a line x feeding level interaction for first rib fat depth. Also there was a tendency (P<.10) for a line x feeding interaction for average fat depth. F and L lines did not differ from the C line for any backfat depth at ad libitum intake, but at limited intake L barrows had less (P<.01) first rib fat and average fat depth than C barrows. At limited intake L barrows also had less (P<.05) 10th rib fat and last rib fat depth than C barrows. At generation five in this population (Woltmann et al., 1993) reported that barrows and gilts from the F line had more fat than barrows and gilts from the C line. Ellis et al. (1983) reported that boars from a line selected for an index of increased ADG and decreased backfat, when evaluated at three different restricted feeding levels, deposited less total fat and less backfat than a control line. McPhee et al. (1988) reported that selection under a restricted intake resulted in decreased backfat in progeny at ad libitum intake. Cameron et al. (1994a) reported that a line of pigs that had been selected for increased lean growth rate at ad libitum intake had less fat when evaluated at ad libitum when compared to a control line. Cameron et al. (1994b) reported that a line of pigs that had been selected for lean growth rate at restricted feeding when evaluated at 75% of predicted ad libitum intake had less fat than the control line. Cleveland et al. (1983) selected for increased ADG and decreased backfat with an economic index. This index weighted daily gain more in standard deviation units than backfat. Barrows from the index and control lines were individually fed starting at 25 kg for a constant time period. Pigs from each line were tested on one of three rations: ad libitum, 91% of predicted ad libitum intake or 82% of predicted ad libitum. The index line had less backfat when evaluated at each intake when compared to the control line. The results of the present study are at least in partial agreement; when evaluated at limited intake, pigs that have been selected to be more efficient at converting energy to lean have less fat.

There were no significant differences for loin eye area among the lines at limited intake, there was a tendency (P<.20) for L barrows to have less loin eye area than C barrows. But when allowed ad libitum intake L barrows had smaller (P<.05) loin eye areas than C barrows. F barrows also had a tendency to have smaller (P<.05) loin eye area as compared to C barrows. Also there was no difference between F, L and C barrows for carcass length.

Barrows allowed ad libitum access to feed were fatter (P<.05) than those that were limit fed. Vandergrift et al. (1985) also reported that barrows allowed ad libitum access to feed were fatter.

While selection for ADG at limited intake generally decreased backfat at limited intake, differences between F, L and C barrows at ad libitum intake were minimal.

Carcass composition traits

Least squares means for carcass composition traits are presented in Table 9. At ad libitum intake F barrows had a lower (P<.05) LEAN % and a higher (P<.05) FAT %. than C barrows. L barrows had a tendency (P<.05) to have a lower LEAN%. There also was a tendency (P<.20) for F and L barrows to have less FFLEAN% than C barrows. A tendency (P<.20) also existed for L barrows to have a higher FAT% than C barrows at ad libitum intake. These differences are also reflected in LEAN, FFLEAN and FAT.

When compared at limited intake, there were no differences between F barrows or L barrows when compared to C barrows for any of the carcass composition traits. However L barrows at limited intake did rank lower for FAT%. There was a line x diet interaction for BONE%. At limited intake, L barrows had a tendency (P<.20) to have a higher BONE% than F or C barrows.

Woltmann et al. (1993) reported that in barrows that were sampled from generation three to five in this population in the spring farrowing group that L barrows were leaner than C barrows. Furthermore no differences were found for fat between F, L or C barrows in the fall farrowing group by Woltmann et al. (1993). Similiar responses were found in barrows sampled from the fall farrowing group for loin eye area, percent lean and cutability. Both F and L barrows had smaller loin eyes , decreased percent lean and a lowered cutability compared to C barrows (Woltmann et al.,1993).

Cleveland et al. (1983) reported that test barrows from a line that had been selected for increased gain and decreased backfat had a higher percentage of lean than control line barrows when evaluated at ad libitum intake, 91% of ad libitum intake, and 82 % of ad libitum intake.

Ad libitum fed barrows were lower (P<.05) for LEAN% and higher (P<.01) for FAT% as compared to limit fed barrows. Vandergrift et al. (1985) also reported that barrows allowed ad libitum access to feed were fatter and had a lower percentage of lean than barrows allowed limited intake.

Lean growth traits

Least squares means for lean growth traits are presented in Table 10. The three lines did not differ for LTG, FFLTG, LTFC and FFLTG at ad libitum intake. However F barrows were lower (P<.05) for LNGA% and FFPLNGA% than control barrows at ad libitum intake. At limited intake F or L barrows did not differ from C barrows for ADG, ADFI, LTG, FFLTG, LTFC, FFLTFC, LNGA% or FFPLNGA%.

Woltmann et al. (1993) reported that F and L barrows sampled from this population at generation three through five in the spring farrowing group had a higher lean gain compared to C barrows.

In a line selected for decreased backfat and increased ADG, the selected pigs were more efficient at lean tissue growth at either ad libitum or restricted feed intake (McPhee, 1981). McPhee et al. (1988) selected for estimated weight of lean ham at the end of a postweaning period that lasted 12 weeks at 85% of predicted ad libitum feed intake. After five generations of selection, select and control line pigs were compared at either limited (85%) or ad libitum access to feed. The selected lines of pigs had a higher lean gain than the control line of pigs at either feeding level. McPhee and Trappett (1987) reported that, in the mouse, a line selected for ADG under limited intake expressed the greatest lean tissue feed conversion regardless of whether the lines were compared at ad libitum intake or limited intake. Contrary to the results in the mouse, there were no differences between barrows from the F, L and C lines for LTG, FFLTG, LTFC and FFLTFC.

Barrows allowed ad libitum intake in the present study also had greater ($P<.01$) LTG and FFLTG while barrows at limited intake had an advantage in LTFC and FFLTFC.

TABLE 8

LEAST SQUARES MEANS FOR CARCASS CHARACTERISTICS FROM BARROWS REPRESENTING FAST (F), LIMIT (L) AND CONTROL (C) LINES AND ALLOWED AD LIBITUM OR LIMITED FEED INTAKE.

	AD LIBITUM			CONTRAST[b]		LIMITED			CONTRAST[b]	
CHARACTERISTIC[a]	F	L	C	F vs C	L vs C	F	L	C	F vs C	L vs C
CFRB, cm.	4.36	4.33	4.26	NS	NS	3.95	3.60	4.17	NS	**
C10th, cm	3.28	3.34	3.34	NS	NS	2.97	2.66	3.18	NS	*
CLRB, cm	2.92	2.84	2.91	NS	NS	2.73	2.31	2.68	NS	*
CLLV, cm	3.39	3.18	3.31	NS	NS	3.07	2.70	3.02	NS	NS
CAFD, cm	3.53	3.48	3.50	NS	NS	3.21	2.85	3.32	NS	**
CLEA, sq. cm	27.0	25.6	30.4	+	*	26.2	25.6	29.1	NS	+
CL, cm	77.7	79.0	78.3	NS	NS	78.4	78.5	79.0	NS	NS

[a]CFRB = Carcass first rib fat depth; C10th = Carcass 10th rib fat depth; CLRB = Carcass last rib fat depth; CLLV = Carcass last lumbar vertebra fat depth; CAFD = Carcass average fat depth; CLEA = Carcass loin eye area; CL = Carcass length.

[b]NS = not significant at P>.20; + = significant at P<.20; * = significant at P<.05; ** = significant at P<.01.

TABLE 9

LEAST SQUARES MEANS FOR CARCASS COMPOSITION TRAITS FROM BARROWS REPRESENTING FAST (F), LIMIT (L) AND CONTROL (C) LINES AND ALLOWED AD LIBITUM OR LIMITED FEED INTAKE.

	AD LIBITUM			CONTRAST[b]		LIMITED			CONTRAST[b]	
TRAIT[a]	F	L	C	F vs C	L vs C	F	L	C	F vs C	L vs C
LEAN %	44.1	44.9	47.6	*	+	46.2	47.7	48.3	NS	NS
FFLEAN%	40.6	41.2	43.8	+	+	43.0	44.1	44.8	NS	NS
FAT %	43.6	42.9	39.8	*	+	41.1	38.1	38.5	NS	NS
BONE %	11.3	11.6	11.8	NS	NS	11.8	13.1	12.3	NS	+
LEAN, kg	34.9	36.1	38.1	*	NS	36.0	37.0	37.8	NS	NS
FFLEAN, kg	32.1	33.1	35.1	*	NS	33.5	34.2	35.2	NS	NS
FAT, kg	34.7	34.1	31.8	*	+	32.0	29.5	30.5	NS	NS
BONE, kg	9.0	9.2	9.4	NS	NS	9.2	10.2	9.8	+	NS

[a]LEAN % = Total lean/carcass weight x 100; FFLEAN % = Fat free lean/carcass weight; FAT % = Total fat/carcass weight x 100; BONE % = Total bone/carcass weight; LEAN= Total lean; FFLEAN = Total fat free lean; FAT = Total fat; BONE = Total bone.

[b]NS = not significant at P>.20; + = significant at P<.20; * = significant at P<.05; ** = significant at P<.01.

TABLE 10

LEAST SQUARES MEANS FOR LEAN GROWTH TRAITS FROM BARROWS REPRESENTING FAST (F), LIMIT (L) AND CONTROL (C) LINES AND ALLOWED AD LIBITUM OR LIMITED FEED INTAKE

	AD LIBITUM			CONTRAST[b]		LIMITED			CONTRAST[b]	
TRAIT[a]	F	L	C	F vs C	L vs C	F	L	C	F vs C	L vs C
LTG, kg/day	.37	.38	.38	NS	NS	.30	.33	.32	NS	NS
FFLTG, kg/day	.34	.34	.35	NS	NS	.28	.31	.30	NS	NS
LTFC, LTG/feed	.11	.12	.12	NS	NS	.12	.13	.12	NS	NS
FFLTFC, FFLTG/feed	.10	.11	.11	NS	NS	.11	.12	.11	NS	NS
LNGA %	35.7	37.7	40.4	*	NS	37.3	39.0	39.5	NS	NS
FFPLNGA %	32.8	34.4	37.1	*	NS	34.8	36.0	36.7	NS	NS

[a]LTG = Lean tissue gain per day; FFLTG = Fat free lean tissue gain per day; LTFC = Lean tissue feed conversion; FFLTFC = Fat free lean tissue feed conversion; LNGA % = LTG/average daily gain x 100; FFPLNGA % = FFLTG/average daily gain x 100.

[b]NS = not significant at P>.20; * = significant at P<.05; ** = significant at P<.01.

Summary

Genetic improvement can be made by selecting for traits of interest. Selection is the only way that permanent changes can be accomplished within a given population. If the swine industry is to remain competitive as a supplier of a protein source, traits that are economically important must be continually improved. Traits such as average daily gain, feed intake, feed efficiency and carcass composition are components of lean growth rate and efficiency. Lines must be developed that focus on lean growth rate and efficiency in an effort to help the swine industry to meet consumer demands for a leaner product at a low cost. In the past the production traits just mentioned have been improved by selecting for one trait individually or by considering several traits together and usually evaluated at ad libitum intake. The more common method of mult-trait selection is through an index. Index selection combines information from two or more traits into a single value for genetic merit based on genetic parameters and the relative economic value of each trait. Fowler et al. (1976) proposed an alternate method for improving lean growth rate and lean tissue feed conversion. Pigs are allowed a standard amount of food over a given period. By standardizing intake, variation in growth rate that is influenced by intake is removed. With some methods of index selection there is downward pressure on intake associated with selection for efficiency (Cameron and Curran (1994a). Fowler et al. (1976) theorized was that selection for increased growth under restricted feeding conditions should avoid downward pressure on intake and favor those animals that are most efficient because they allocate more metabolizable energy toward the synthesis of protein and less toward fat. If the above theory holds true then selection for growth under a restricted intake should favor lean growth efficiency because feed intake is a constant.

The theory proposed by Fowler et al. (1976) has been tested in three studies using mice (McPhee et al., 1980; Hetzel and Nicholas, 1986; McPhee and Trappett, 1987) and two studies using pigs (McPhee et al., 1988 and Cameron et al., 1994b).

Two criticisms that perhaps could be made of McPhee et al., (1980) are that selection occurred over an age range (5 to 9 weeks) that was beyond the period of rapid lean deposition in the mouse, and 2) a line selected for increased growth at ad libitum feed intake was not included. The two latter studies in the mouse corrected these problems by selecting for increased weight gain from 3 to 6 weeks at ad libitum intake and restricted feed intake.

The objectives of the present study were (1) to evaluate lean growth rate and lean tissue feed conversion in lines of pigs that had been selected for gain under allowed ad libitum or a standard limited intake and (2) to compare response in component traits of lean growth rate and lean growth efficiency (i.e. growth rate, feed intake, feed efficiency and compositional differences). The objectives test the hypothesis that response will differ depending on the allowed intake level under which selection occurs. The design used to test the proposed hypothesis included lines of pigs selected for increased growth under: 1) ad libitum intake and 2) a standard limited intake (83% of predicted ad libitum intake). A relaxed selection control was also maintained to account for environmental fluctuations. In this evaluation, pigs selected under ad libitum intake had an advantage in ADG over control pigs when fed at ad libitum intake but pigs selected under standard limited intake did not show a clear advantage in gain at ad libitum intake. The response in gain to selection at ad libitum intake is in agreement with all prior reports in the pig (Fredeen and Mikami, 1986e; Kuhlers and Jungst, 1991a; Kuhlers and Jungst, 1991b; Woltmann et al., 1992; Cameron and Curran, 1994a). In contrast, results of the limited intake line differs from previously reported results. Selection in mice (Hetzel and Nicholas, 1986; McPhee and Trappett, 1987) and pigs (McPhee et al., 1988) under a restricted intake resulted in positive response in gain by progeny allowed ad libitum access to feed.

Based on previous experimental results in the mouse (Hetzel and Nicholas, 1986; McPhee and Trappett, 1987) and swine (McPhee et al., 1988), one might expect that selection for growth under a limited intake would increase growth at ad libitum or restricted intake. However in the present evaluation of the lines, selection under the standard limited intake level did not significantly change growth rate.

One potential reason for the lack of response in growth is that the recommended daily intake of protein was not met throughout the test period. Due to the restriction in actual amount of feed, boars may have been deficient in the amount of total protein they received. If dietary protein was not sufficient to meet the pig's requirement for maximum growth, the animal was not able to express its full potential for growth under restricted feeding. This may have lowered the variation in growth expressed by the boars thus causing error in identifying those boars that have the most genetic merit for gain. Another possible reason could have been that the initial line that the ad libitum and restricted lines had been created from had already been selected for increased growth. It is possible that selection limits may have been approached.

The present evaluation of selected barrows at generation 7 indicated an increase in intake between the line selected at ad libitum intake and the relaxed selection control. At generation five in this same population Woltmann et al. (1993) reported that barrows and gilts evaluated in the F line had higher feed intakes than barrows and gilts from the C line. Also progeny from the L line had slightly lower intakes than C line progeny. The increased daily intake in the ad libitum line agrees with other studies in the pig (Woltmann et al., 1992; Cameron and Curran 1994a) and studies in mice (Hetzel and Nicholas, 1986; McPhee and Trappett, 1987). The present study also indicated no change in intake for the limit line compared to the control line at ad libitum intake. This is in agreement with the results that were reported by Hetzel and Nicholas (1986) in the mouse. But contrasting results were reported by McPhee and Trappett (1987). They reported a decrease in ad libitum intake in a line of mice selected under restricted intake.

In this study feed efficiency in the ad libitum line was unaffected by selection, but feed efficiency responded favorably in the line selected under limited intake when evaluated at either level of intake. Cameron and Curran (1994) reported that pigs selected for daily food intake ate more food in total, on a daily basis, grew faster but consumed more feed per kilogram of gain than pigs that had been selected for lean growth and lean food conversion. Feed efficiency in lines of mice selected under ad libitum intake responded favorably (Hetzel and Nicholas, 1986; McPhee and Trappett, 1987). The results from restricted intake lines of mice (Hetzel and Nicholas, 1986; McPhee and Trappett, 1987) and pigs (McPhee et al., 1988) are in agreement with the feed efficiency ratios in the present study.

If selection for growth rate occurs under a standard limited intake, it would be expected that feed efficiency will improve. If feed consumption is held at a constant and fast gaining pigs are selected, then pigs with the most desirable feed:gain ratio will be selected. This study and prior experiments (Hetzel and Nicholas, 1986; McPhee and Trappett, 1987; McPhee et al., 1988) agree with this theory.

Means for carcass backfat measurements indicate that response was similar for standard limited intake line and ad libitum intake line when compared to the control line at ad libitum intake. But at limited intake, line means indicate that response in backfat thickness at a constant weight was favorable in the limited intake line and was not different from the control in the ad libitum line. McPhee et al. (1988) also reported decreased backfat as the result of selection for increased ham weight under a restricted intake level.

Fat as a percentage of carcass weight was higher in the ad libitum line when compared to the control line at ad libitum intake. There was no difference between the ad libitum line or limited intake line when evaluated at limited intake. These results are somewhat different from what was reported in the mouse. Fat as a percentage of total body weight did not change in a line that had been selected at ad libitum intake and decreased in a restricted line (Hetzel and Nicholas, 1986).

The results of the present evaluation are at least in partial agreement with the results of selection for an index that included growth rate, feed efficiency and backfat (McPhee, 1981; Henderson et al., 1982). These studies suggest that improvement in the selection objective of lean growth efficiency was due to a favorable response in gross efficiency and a decrease in backfat. This improvement in efficiency and backfat however resulted in a decrease in backfat. Intake is positively correlated with growth rate. Due to the fact that growth rate is a trait of major economic importance it is essential that feed intake levels be maintained in selection programs.

The evaluations made in the present study may suggest that whatever environment in which selection occurred is the environment in which that expression of selection may be the greatest. The line selected at ad libitum intake certainly expressed the greatest gain in that environment. The line that was selected at restricted intake ranked higher for growth rate and efficiency in that environment. In the ad libitum line, response in ad libitum fed progeny was positive for growth rate and feed intake, but responses for feed efficiency and backfat are not different from the control line. Positive responses for feed efficiency in ad libitum fed progeny from the standard limited intake line contrasts with the results of the same traits in the ad libitum line.

Results from this evaluation indicate that the ad libitum line or restricted intake line do not differ from the control line for lean gain or lean tissue feed conversion when progeny are evaluated at ad libitum intake or restricted intake. It does appear that at ad libitum intake the ad libitum line had lower lean content when expressed as a percentage of carcass weight. The same line also had more fat when expressed as a percentage of carcass weight. Also at ad libitum intake, the ad libitum line progeny had a lower ratio of lean gain per day expressed as a percentage of average daily gain. It appears that selection for growth at ad libitum intake or restricted intake has not changed the lean component of growth. Differences expressed between these lines can be attributed to fat tissue deposition.

One possible explanation for the lack of response in lean gain or lean tissue feed conversion is that the restricted line was not only restricted in total amount of feed received but also may have been restricted in terms of total protein available for lean growth. A possible correction for this deficiency would be to increase protein density in the diet. If adequate protein is not available then we may not be able to select the animals that actually have the best genetic merit for lean growth. Stern et al. (1994) reported that pigs that had been selected for lean tissue growth rate expressed the highest lean tissue growth rate when fed high protein diets as compared to low protein diets.

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APPENDIX

TABLE 11

PROBABILITY LEVELS FOR THE INDEPENDENT VARIABLES IN THE MODEL FOR THE GROWTH TRAITS[a]

INDEPENDENT VARIABLE	ADG	ADFI	FE	FC
LINE	.014	.142	.009	.005
DIET	.0001	.0001	.011	.011
LINE * DIET	.168	.153	.757	.729
FARROWING SEASON (FS)	.121	.001	.129	.102
LINE*FS	.148	.049	.371	.328
DIET*FS	.0009	.001	.225	.229
LINE*DIET*FS	.143	.031	.940	.940
WEIGHT (WT)	NS	NS	NS	NS
WEIGHT^2 (WT2)	NS	NS	NS	NS
WT*LINE	NS	NS	NS	NS
WT*DIET	NS	NS	NS	NS
WT*FS	NS	NS	NS	NS
WT2*LINE	NS	NS	NS	NS
WT2*DIET	NS	NS	NS	NS
WT2*FS	NS[b]	NS	NS	NS

[a]ADG = Average daily gain; ADFI = Average daily feed intake; FE = Feed efficiency; FC = Feed conversion.
[b]The probability level was >.20 in the full model and thus they were removed from the final (reduced) model.

TABLE 12

PROBABILITY LEVELS FOR THE INDEPENDENT VARIABLES IN THE MODEL FOR CARCASS TRAITS[a]

INDEPENDENT VARIABLE	CFRB	C10th	CLRB	CLLV	CAFD	CLEA	CL
LINE	.141	.193	.034	.160	.020	.004	.238
DIET	.0003	.002	.112	.005	.0001	.477	.079
LINE*DIET	.059	.188	.191	.807	.055	.849	.355
FARROWING SEASON (FS)	.183	.318	.005	.170	.118	.0001	.0001
LINE * FS	.412	.075	.011	.020	.039	.004	.569
DIET * FS	.792	.494	.188	.789	.842	.913	.967
LINE * DIET * FS	.058	.437	.298	.180	.077	.035	.427
WEIGHT (WT)	.025	NS	.140	NS	NS	NS	.002
WEIGHT2 (WT2)	.026	NS	NS	NS	NS	NS	NS
WT * LINE	NS	NS	NS	NS	NS	NS	NS
WT * DIET	NS	NS	.097	NS	NS	NS	.077
WT * FS	.18	NS	NS	NS	NS	NS	NS
WT2 * LINE	NS	NS	NS	NS	NS	NS	NS
WT2 * DIET	NS	NS	NS	NS	NS	NS	NS
WT2 * FS	NS[b]	NS	NS	NS	NS	NS	NS

[a]CFRB = Carcass first rib fat depth; C10th = Carcass 10th rib fat depth; CLRB = Carcass last rib fat depth; CLLV = Carcass last lumbar vertebra fat depth; CAFD = Carcass average fat depth; CLEA = Carcass loin eye area; CL = Carcass length.

[b]The probability level was >.20 in the full model and thus they were removed from the final (reduced) model.

TABLE 13

PROBABILITY LEVELS FOR THE INDEPENDENT VARIABLES IN THE MODEL FOR CARCASS COMPOSITION TRAITS[a]

INDEPENDENT VARIABLE	LEAN%	FFLEAN%	FAT%	BONE%	LEAN	FFLEAN	FAT	BONE
LINE	.030	.056	.022	.025	.146	.105	.057	.024
DIET	.030	.015	.003	.0002	.420	.241	.0002	.144
LINE * DIET	.607	.654	.281	.127	.692	.726	.186	.180
FARROWING SEASON (FS)	.436	.504	.200	.536	.135	.158	.502	.185
LINE * FS	.047	.039	.024	.008	.035	.027	.040	.006
DIET * FS	.593	.576	.911	.471	.733	.716	.573	.115
LINE * DIET * FS	.102	.129	.065	.114	.208	.296	.063	.115
WEIGHT (WT)	NS	NS	NS	.012	.196	.329	.166	.0001
WEIGHT2 (WT2)	NS	NS	NS	NS	NS	NS	NS	NS
WT * LINE	NS	NS	NS	NS	.161	.116	NS	NS
WT * DIET	NS	NS	NS	NS	NS	NS	NS	.130
WT * FS	NS	NS	NS	NS	NS	NS	NS	NS
WT2 * LINE	NS	NS	NS	NS	NS	NS	NS	NS
WT2 * DIET	NS	NS	NS	NS	NS	NS	NS	NS
WT2 * FS	NS[b]	NS	NS	NS	NS	NS	NS	NS

[a]LEAN % = Total lean/carcass weight x 100; FFLEAN % = Fat free lean/carcass weight x 100; FAT % = Total fat/carcass weight x 100; BONE % = Total bone/carcass weight x 100; LEAN = Total lean; FFLEAN = Total fat free lean; FAT = Total fat BONE = Total bone.

[b]The probability level was >.20 in the full model and thus they were removed from the final (reduced model).

TABLE 14

PROBABILITY LEVELS FOR THE INDEPENDENT VARIABLES IN THE MODEL FOR THE LEAN GROWTH TRAITS[a]

INDEPENDENT VARIABLE	LTG	FFLTG	LTFC	FFLTFC	LNGA %	FFPLNGA %
LINE	.527	.705	.238	.374	.115	.082
DIET	.0001	.0001	.063	.046	.529	.304
LINE*DIET	.778	.801	.828	.838	.561	.627
FARROWING SEASON (FS)	.098	.103	.862	.822	.303	.234
LINE * FS	.231	.230	.118	.116	.060	.039
DIET * FS	.046	.052	.622	.599	.742	.716
LINE * DIET * FS	.496	.485	.346	.337	.265	.353
WEIGHT (WT)	NS	NS	NS	NS	.422	.325
WEIGHT^2 (WT2)	NS	NS	NS	NS	NS	NS
WT * LINE	NS	NS	NS	NS	.125	.090
WT * DIET	NS	NS	NS	NS	NS	NS
WT * FS	NS	NS	NS	NS	NS	NS
WT2 * LINE	NS	NS	NS	NS	NS	NS
WT2 * DIET	NS	NS	NS	NS	NS	NS
WT2 * FS	NS[b]	NS	NS	NS	NS	NS

[a]LTG = Lean tissue gain per day; FFLTG = Fat free lean tissue gain per day; LTFC = Lean tissue feed conversion; FFLTFC = Fat free lean tissue feed conversion; LNGA % = LTG/average daily gain; FFPLNGA % = FFLTG/average daily gain.

[b]The probability level was >.20 in the full model and thus they were removed from the final (reduced) model.

TABLE 15

FORMULAS USED TO CALCULATE OR DEFINE CARCASS AND CARCASS COMPOSITION TRAITS

CFRB = midline carcass backfat depth measured at the first rib in cm.
C10th = midline carcass backfat depth measured at the 10th rib in cm.
CLRB = midline carcass backfat depth measured at the last rib in cm.
CLLV = midline carcass backfat depth measured at the last lumbar vertrabra in cm.
CAFD = carcass average fat depth: (CFRB + CLRB + CLLV) / 3.
CLEA = carcass loin eye area in sq. cm. measured at the 10th rib.
CL = carcass length measured in cm from the first rib to the aitch bone in the ham.
LEAN = Total lean.

Special Note: Due to labor restrictions some carcasses were chilled an excessive amount of time which caused some dehydration and moisture loss from the carcass. Moisture loss was arrived at by substracting right side weights from right side hot carcass weights. Since a large proportion of moisture loss came from the muscle and a small proportion from fat. Moisture loss reallocated back into the muscle and fat tissue in the following way.

LEAN = MOISTURE LOSS + Lean weight after fabrication.
MOISTURE LOSS = TOTAL MOISTURE LOSS x 7/8 since muscle is approximatley 70% water.
FFLEAN = Total fat free lean; Total lean- (Total lean x fat % determined by ether extract).
FAT = MOISTURE LOSS + Fat weight after fabrication.
MOISTURE LOSS = TOTAL MOISTURE LOSS x 1/8 since fat is approximatley 10% water.
BONE = Total bone.
LEAN% = Total lean/carcass weight x 100.
FFLEAN% = Fat free lean/carcass weight.
FAT% = Total fat/carcass weight x 100.
BONE % = Total bone/carcass weight x 100.

TABLE 16

CALCULATIONS AND METHODS OF ANALYSIS USED TO DETERMINE SELECTION DIFFERENTIALS

Unweighted selection differentials for males = ADG means for selected boars - ADG means for all boars "within a generation farrowing group line subclass"

Weighted selection differentials for males = Each ADG record for each boar was weighted proportionally by the number of progeny that boar produced: For each boar ADG x (no of progeny/total number of progeny produced that generation).

This simply created a weighted ADG record for each boar.

Weighted ADG means for selected boars - ADG means for all boars "within a generation farrowing group line subclass"

Standardized weighted selection differentials for males = weighted selection differentials/ phenotypic standard deviation
Phenotypic standard deviation for L boars = .047
Phenotypic standard for F and C boars= .098

Unweighted selection differentials for females = LSMEANS for selected gilts - LSMEANS for all gilts " within a generation farrowing group line subclass"

Note: Gilts were subjected to number of different feeding trials throughout the seven generations of selection so their gains had to be corrected for the different diets to which they were exposed. This model included line and diet as sources of variation.

Weighted selection differentials = LSMEANS for weighted ADG for selected gilts-LSMEANS for weighted ADG for all gilts for females "within a generation farrowing group line subclass".

Note: The same model was used to analyze weighted selection differentials as unweighted selection differentials and also weighted selection differentials were calculated in the same way as the weighted selection differentials for boars.

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