# GROWTH AND CARCASS OF PIGS SELECTED FOR RAPID OR SLOW POSTWEANING GROWTH AND FED AD LIBITUM OR LIMITED RATIONS

By

MICHAEL DAVID WOLTMANN

Bachelor of Science in Animal Science

Northwest Missouri State University

Maryville, Missouri

1986

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 1989

GROWTH AND CARCASS OF PIGS SELECTED FOR RAPID OR
SLOW POSTWEANING GROWTH AND FED AD LIBITUM
OR LIMITED RATIONS

Thesis Approved:

David S. Buchanan
Thesis Adviser

Rodney D. Geisert

Charles V. Maxwell

Norman N. Durham
Dean of the Graduate College

## ACKNOWLEDGEMENTS

I wish to thank Dr Archie Clutter for his patience, advise and criticisms while I was preparing this thesis. Just as many thanks are due to Dr David Buchanan for getting my graduate studies started in the proper direction and his knowledge of this project. I would also like to thank Drs Charles Maxwell and Rodney Geisert for serving as committee members and for their helpful suggestions in preparation of this manuscript.

I would also like to extend my appreciation to those who were involved in the collection of these data; especially David McLaren, Ron Bates and Rex Vencl and the rest of his farm crew at Fort Reno.

Thanks are also due to Larry Burditt for the answers to my many computer questions. I would also like to say thanks to all my fellow graduate students for sharing friendship and knowledge, especially Eugene Tinker.

Most of important of all is my family who have supported me throughout my undergraduate and graduate studies. My parents, Dave and Mary Woltmann, have encouraged me all the way for which I am grateful. And finally, a very special thanks to my wife Gayle and son Darrin who have been my biggest supporters since arriving at Oklahoma State.

# TABLE OF CONTENTS

LIST OF TABLES

| Table | | Page |
|---|---|---|

## LIST OF FIGURES

## NOMENCLATURE

| | |
|---|---|
| ADG | average daily gain |
| AL | ad libitum level of intake |
| BW | body weight |
| cm | centimeters |
| d | day |
| EE | percent ether extract |
| F/G | feed:gain |
| g | gram |
| kg | kilograms |
| LIM | intake limited to 83 % of predicted ad libitum |
| LTGR | lean tissue growth rate |
| LTFC | lean tissue feed conversion |
| min | minute |
| mm | millimeters |
| RGL | rapid growth line |
| SGL | slow growth line |
| wt | weight |
| yr | year |

# CHAPTER I

## INTRODUCTION

The swine industry has became more competitive in recent years, forcing producers to maximize efficiency of production. A number of traits are included in overall efficiency, including conception rate, litter size, weight at weaning, postweaning average daily gain, efficiency of gain and carcass backfat. Permanent changes in any of these traits can only be accomplished through genetic improvement. Two primary ways in which genetics can be used to improve livestock populations are crossbreeding and selection. Advantages of crossbreeding are heterosis, due to an increase in heterozygosity, and breed complementarity. In general, reproductive traits such as litter size benefit most from crossbreeding. Selection increases the frequency of desirable genes for a particular trait and is dependent on additive genetic variance. The most benefit from selection is seen in growth and carcass traits. Both methods of genetic improvement are very important for increasing the overall efficiency of swine production; however, for continuous improvement to occur selection must be practiced.

Selection for growth, feed efficiency, and backfat has been successful in lines of pigs. Unfortunately, correlated response in one or more traits of importance is often unfavorable when single-trait selection for growth is practiced. For this reason, combining traits into an index is often desirable to maximize overall efficiency.

The postweaning goal of the swine industry should be the production of lean as quickly and efficiently as possible under ad libitum diets. Two traits of importance, as defined by Fowler (1976), are lean tissue feed conversion (LTFC) and lean tissue growth rate (LTGR). In many European countries, restriction of feed in market swine is common due to high feed costs relative to market price and premiums based on lean content of the carcass. Neither of the above conditions are currently the case in the United States; however, evaluation of performance from pigs selected on ad libitum diets and fed restricted diets would be of interest if either condition changes.

Selection for rapid postweaning gain under a restricted diet may be an alternative method to identify individuals that are superior in efficiency of lean growth. If variation in feed intake is removed, pigs with the fastest growth rate should be the individuals that deposit lean most efficiently, because deposition of lean is much more efficient than deposition of fat.

The objectives of this study are to 1) evaluate differences in LTGR and LTFC in lines selected for divergent postweaning daily gain; 2) compare differences in LTGR and LTFC when variation in feed intake is eliminated and 3) examine the relationship between LTFC and LTGR and other carcass and growth traits in barrows fed either ad libitum or restricted diets.

# CHAPTER II

# REVIEW OF LITERATURE

## Selection for Growth in Swine

### Direct Response

Selection for postweaning gain in swine was first reported by Krider et al. (1946). Two lines of Hampshire swine were selected for either high or low weight at 150 days of age. The high line was significantly heavier at 56, 150 and 180 days after four generations of selection. After nine generations of selection there was a 28.1 kg difference between the lines at 180 days (Baird et al., 1952). Most of this difference was established postweaning, where over a 72 day period high-line pigs gained .43 kg/d, versus .14 kg/d in the low line. Selection for gain or increased body weight (BW) was practiced in a number of inbred lines (Laben and Whatley, 1947; Kottman et al., 1948; Fine and Winters, 1953). In these lines improvement from selection was often less than decreases in gain due to inbreeding depression. Durocs selected for increased BW were 10 kg heavier at 180 days than an unselected line, but BW declined by 15 kg due to inbreeding (Laben and Whatley, 1947). At 154 days of age BW declined in one line selected for increased BW, while it increased slightly in another line (Fine and Winters, 1953). Selection for gain from 56 days of age to 90 kg was successful and will be discussed, as compared to an index line (gain and backfat) selected under the same conditions, in a later section (Sather and Fredeen, 1978; Fredeen and Mikami, 1986b).

Selection for small body size at 140 days of age resulted in a 29 % decrease in size seen over an 11 year period (Dettmers et al., 1965). Selection for postweaning gain from 42 days of age through 89 kg in a Lacombe herd showed an average response of .0082 kg/generation over seven generations (Rahnefeld, 1973). Response increased over four additional generations of selection (Rahnefeld and Garnett, 1976). An increase in daily gain of .146 kg/d was reported through 11 generations of selection.

More recently selection for high 70-day weight in Landrace (Jungst and Kuhlers, 1987a), high 200-day weight in Landrace (Kuhlers and Jungst, 1986) and high 200-day weight in Durocs (Kuhlers and Jungst, 1987) has been successful, as compared to control lines. After three generations changes of 3.2 and 4.2 kg/generation were seen in 154- and 200-day weight, respectively (Kuhlers and Jungst, 1987), while a change of about 1.1 kg/generation was seen in 70-day weight (Jungst and Kuhlers, 1987a).

Correlated Responses

Fast-gaining Hampshire swine consume more feed/day and are more efficient than slow-growing Hampshires (Baird et al., 1952). After seven generations of selection for postweaning gain Rahnefeld (1973) reported a decrease of 4 kg of feed per 100 kg of gain. Landrace barrows from a line selected for increased 200-day weight had larger loin eye area, higher percent lean cuts and decreased 10th-rib backfat at 100 kg (Kuhlers and Jungst, 1986). It should be noted that these results were only after three generations of selection. There was no change in probed backfat at 100 kg in Durocs selected at 200 days; however, backfat increased .07 cm/generation at 200 days of age (Kuhlers and Jungst, 1987). Over four generations, change per generation in 154- and 200 day-weight was 3.2 and 4.2 kg, respectively. Carcass information from the same generation taken at about 104 kg indicates that backfat at this weight increased (.07 cm/generation), while percent lean decreased (Jungst and Kuhlers, 1987b).

### Summary of Selection for Growth

Successful selection for increased BW or growth rate and decreased BW has been reported in a number of studies, with the age or period of selection varying. Selection for incresed growth rate appears to occur through higher feed intake and improved efficiency, however there is no clear indication of correlated responses in carcass traits from the studies reviewed.

## Selection for Growth in Mice and Rats

Numerous studies have demonstrated successful single-trait selection for postweaning growth or large BW at a given age in mice and rats. The main focus of this discussion will be correlated response to selection for growth, rather than direct response.

A number of authors have reviewed literature on selection for increased gain or BW in the mouse (Sutherland et al., 1974; Roberts, 1979; McCarthy, 1980; Malik, 1984). In general, all authors indicate that selection for increased gain, resulted in an increase in fat and decrease in feed/gain ratio (F/G). The main effects of selection for increased size on body composition were increased deposition of adipose tissue and a decrease in water, with protein remaining fairly constant (McCarthy, 1980). In lines selected for decreased growth rate there was a decrease in fat and an increase in water. Even though selection for fast growth resulted in large differences in body composition at a given age, these differences were smaller at a constant weight (Sutherland et al., 1974). The increase in gross efficiency (total gain/intake) was due mainly to the mouse's ability to consume more food (Sutherland et al., 1974). However, there appeared to be little difference in net efficiency (lean gain/intake) of tissue growth. Malik (1984) indicated that the age mice are selected for increased BW appears to affect fat deposition. Selection for increased BW at younger ages appears to result in larger increases in fat at a constant weight than mice selected at an older age. The largest difference in gross efficiency between large and control and/or small lines appears in the first two weeks postweaning (Malik, 1984). This difference declined steadily and leveled off at 6 to 8 weeks of age.

Individual studies involving selection for weight gain or BW in the mouse will be separated into two sections. The first discussion will involve experiments in which upward selection for weight gain was included. No lines were found in which there was downward selection for gain. The second section includes those studies with divergent selection for BW. Lines selected for increased gain will be referred to as either fast or rapid, while lines selected for increased and decreased size will be referred to as large and small lines.

Fast Versus Control Lines in Mice

Selection for increased gain from 3 to 6 wk resulted in a one percent response per generation (Kownacki et al., 1979). Control mice had a higher percent carcass protein; however, fast-line males were more efficient in converting food into protein gain. Canolty and Koong (1976) reported rapid-line mice used metabolizable energy available for gain (MEA) more efficiently. No difference in the lines were detected in the amount of MEA deposited as lean, but the fast line deposited a larger percent of MEA as fat (79 vs 58 %). Contrary to this, Timon et al. (1970) reported no difference in protein gain/MEA between control and fast lines selected from 3 to 6 weeks of age. Fat increased in two of three select line replicates of mice selected for gain at older ages (4 to 11 weeks), as indicated by a positive regression of ether extract (EE) on generation of selection (Biondini et al., 1968). On a percentage carcass weight basis, EE was similar between the lines.

Mice selected for average daily gain (ADG) from 3 to 6 weeks of age gained 53.1 % more than controls (Brown and Frahm, 1975). Response in gain was due to a combination of 29.6 % more food consumed and a 21.6 % decrease in F/G. Carcass data from the same mice taken at 21, 42 and 56 days of age showed no line differences in EE (Brown et al., 1977). Selection increased growth of lean and fat; however, proportionately no differences were seen at any of the slaughter ages. Fat depots of select and control mice were compared at specific degrees of mature body weight (Eisen, 1987). Relative rate of maturity was similar between the lines for all depots; however, fast-line mice were later maturing in their pattern. Once each line exceeded 50 % of maturity, all depots were heavier in the fast line.

Growth curves of control and fast (3 to 6 week gain) lines selected for nine generations were very similar in shape (Timon and Eisen, 1969). The inflection point was near 42 days in both lines, with most of the weight difference already present at this age. Feed consumption curves indicated peak intake occurred very near the time of peak gain (day 40) (Timon and Eisen, 1970). Energetic efficiency, defined as energy of eviscerated carcass/energy consumed, was significantly higher in the selected line (Timon et al., 1970).

Large Versus Small Lines in Mice

The largest difference in growth occurred between day 12 and 35 in lines selected 20 generations for large and small 6-week BW (Fowler, 1958). The large line gained approximately three times that of the small line at the peak growth rate of each line. This period of rapid growth was followed by rapid fat deposition between 35 to 60 days in the large line, while the small line failed to reach the stage where most of the gain was due to fat. Selection for increased BW affected protein and fat gain, while selection for decreased BW mainly affected protein and water gain. Energetic efficiency of the large line was higher prior to 4 weeks, and during the period of rapid fat deposition (after 6 weeks) (Fowler, 1962).

In lines selected in the same manner as described above, large-line mice gained 2.5 times faster than small-line mice at the peak growth rate of each line (Lang and Legates, 1969). Maximum gain in the large and control lines was between 24 and 38 days, while it occurred somewhat later in the small line (26 to 45 days). The large-line mice were more efficient from 3 to 8 weeks; however, there was no difference between the control and small lines. There were no fat or protein differences detected in any of the lines, as seen by weekly slaughter data taken from 3 to 8 weeks. Similar results were found in mice slaughtered at 15, 20 or 25 days, where no consistent differences in fat were found between large, control and small lines selected at 6 weeks for BW (Stainer and Mount, 1972). In lines selected for either large or small 8-week weight, small mice deposited less fat and more protein, suggesting a possible alteration in the growth hormone-insulin balance (Stephenson and Malik, 1984). Lines selected for high 8-week weight were more lean than control mice up to 4 weeks, after this point large-line mice deposited more fat at an increasing rate (McPhee and Neill, 1976). The age at which maximum fat deposition occurred in large mice decreased from generations 14 to 25. By 5 weeks of age most of the difference in weight between large and control lines was already present. However, control and small lines were similar at 5 weeks and diverged from that point.

The amount of downward and upward response from controls varied. Similar response (34 and 41 %) in small and large lines was reported by Fowler (1958). Changes in BW were symmetrical in lines selected by McPhee and Neill (1976), while twice as much downward response was seen by Lang and Legates (1969), (28 vs 14 %).

Hayes and McCarthy (1976) selected lines of mice for high (H5) or low (L5) 5-week weight, high (H10) or low (L10) 10-week weight or an unselected control. When compared at 5, 10 and 21 weeks of age, H5 mice were fatter than H10 mice, while in comparing the low lines, L10-line mice were fatter. This suggests that selection operated on variation in feed consumption. Large-line mice selected at a younger age were fatter due to an increase in daily feed consumption. Selection for high BW at 10 weeks seemed to favor those individuals with high consumption that utilized a relatively small portion of what was consumed for production of fat. Growth curves of the lines from 3 to 21 weeks of age were similar in shape within the high and low lines (McCarthy and Bakker, 1979). Most of the weight difference between large and small lines occurred between 3 and 6 weeks, with growth rate leveling off after this period in all lines. Fat distribution differed between large and small lines (Allen and McCarthy, 1980). Fast-growing fat depots made a greater contribution to total dissected fat in the high lines and it was concluded that selection for growth can affect the relative rate of fat deposition if fat is deposited prior to age of selection.

## Effects of Limited Intake on Selected Lines

A number of lines selected for gain or BW under ad libitum conditions have been fed restricted diets to aid in determining the major correlated responses causing the change in growth rate. Fast-line mice gained more and were more efficient than controls, when both lines were fed restricted diets (Timon and Eisen, 1970). Differences in feed efficiency between the lines were greater under limit feeding. Carcass data on these lines show no differences in protein, EE, water or fat-free lean as a percent of carcass weight when comparing ad libitum versus limit feeding (Timon et al., 1970). Feed restriction in rapid-line mice resulted in a larger portion of available energy being deposited as lean tissue, even though total lean deposition decreased

(Canolty and Koong, 1976). Stainer and Mount (1972) restricted large and control lines to 4.0 g/d and the small line to 3.5 g/d. A comparison of carcass data from these two lines indicated large-line mice retained 6.7 kcal of energy over an 18 day period, as compared to 4.2 kcal in the control line. Even though large-line mice were consume food at a smaller percentage of BW, they grew faster than controls. Small-line mice were not restricted by 3.5 g, and as a result gained more than controls. The fact that differences in BW were maintained between fast and control lines on the same daily intake does not support the theory that daily intake is the primary correlated trait when selecting for growth.

Growth curves were very similar in the small line under both diets (Stainer and Mount, 1972). Ad libitum fed mice had higher growth rates, however the shape of the large and control line curves for each diet were very similar. When restricted to the control line level of intake, large mice gained less and were less efficient from 3 to 6 weeks (Roberts, 1981). This was the opposite the results of Stainer and Mount (1972). Lines selected for high and low 6-week weight were fed either full or restricted (75 % of full) diets from 5 to 8 weeks (Cartwright et al., 1980). All lines lost weight on the limited diets, with small-line mice losing the least. Total body energy, from weekly slaughter data, was highest in large-line mice for both diets, followed by control- then small-line mice.

Rapid Versus Slow Lines in Rats

Selection for rapid or slow gain between 3 to 9 weeks resulted in heavier BW at 3, 6 and 9 weeks of age in the rapid line (Baker and

Chapman, 1975). No difference in 3-week weight was seen between control- and slow-line rats. Gain over the selection period resulted in most of the weight difference between the selected lines. Select lines did not differ in fat content; however, both were more lean than the control line. Rios et al. (1986) looked at the same lines after 24 additional generations of selection. From 3 to 9 weeks the fast line gained 11 % more than controls and the slow line 8 % less than controls. Most of the difference in efficiency between the selection lines was from 6 to 9 weeks of age, when the fast line were 9 % more, and the slow line 8 % less efficient than controls. Though not significant, both select lines had more fat than controls, differing from Baker and Chapman's (1975) findings.

Maintenance Requirements of Selected Lines

Maintenance energy estimates are not consistent across experiments. In his review, Malik (1984) hypothesized small mice spend more energy for maintenance by dissipating more heat because of a larger surface area per unit of body weight. Results of Stephenson and Malik (1984) and Roberts (1980) are in agreement with this theory. Two studies reported that high-line mice require more energy for maintenance (Timon et al., 1970; Cartwright et al., 1980), but no differences between rapid and control lines were reported by Canolty and Koong (1976). At the same age, energy expenditure was higher in large-line mice, while at the same weight there was no difference between large, control or small lines (Fowler, 1962). It was noted that large-line mice generally displayed more activity, but body activity did not appear to restrict or determine growth in either line. In rats, lines selected for growth rate were not different for estimated maintenance requirements corrected for body weight (Rios et al., 1986).

Summary of Selection for Growth in Mice

Fast or large lines, as compared to control and/or small lines, are in general more efficient, consume more food and have increased amounts of fat. The higher intakes in large or fast lines are utilized to a large extent for deposition of fat. The shape of growth curves and age of inflection were not different between fast and control lines. The largest difference in growth between lines selected for large and small size appears to occur between 2 and 5 weeks of age. At peak growth rate large-line mice gain from 2.5 to 3.0 times more than small lines, with peak gain occurring at an older age in small-line mice. Age of selection effects fat deposition; as lines selected for growth at younger ages deposit more fat than those selected at older ages. There is also some indication that selection for gain may affect tissue distribution.

The effect of limit feeding is not totally clear; however, in general it appears large or fast mice gain more and are more efficient than controls, indicating that efficiency is the major correlated trait associated with selection for growth. However, one study reported decreased gain and efficiency in large-line mice when they were fed at the level of controls. This would indicate that intake is the major correlated trait. Growth curves were very similar between large and control lines under limited nutrition. Also, there is disagreement between studies on how selection for growth affects maintenance requirements.

## Selection for Postweaning Gain Under Limited Nutrition

Response in Mice and Rats

Selection for high or low growth, under either a high or low plane of nutrition, was practiced from 3 to 6 weeks in mice (Falconer, 1960; Dalton, 1967). No control line was present in Falconer's study. Second litters were used to study growth under the diet opposite of which they were selected. Selection for growth on a high plane of nutrition improved growth only when fed the diet on which they were selected, while selection on a low plane improved growth when fed either diet (Falconer, 1960). When lines selected for high growth were fed on a high plane of nutrition, those selected on limited diets were more lean. Contrary to this, Dalton (1967) found no advantage to selecting for growth under the poorer condition; the diet which they were selected under and the alternative diet were similar throughout. When comparing fast and slow lines selected under full nutrition, similar upward and downward response to selection was seen. However, for selection under limited nutrition very little upward response was seen, while downward response was similar to that seen under full nutrition (Dalton, 1967).

Lines were selected for rapid growth under ad libitum or 83 % of ad libitum from 3 to 6 weeks (Hetzel and Nicholas, 1982) and under restricted conditions from 5 to 9 weeks (McPhee et al., 1980). Both studies included a control line for each method of selection. After six generations of selection, mice were studied on full or limited diets from 5 to 9 weeks (McPhee et al., 1980). Both select line replicates were more efficient on full feed; however, the select lines were similar to controls when fed restricted diets. Hetzel and Nicholas (1982) found feed efficiency improved at the same rate in the two selected lines, while response in 3 to 6 week gain was twice as high in the ad libitum line when mice were measured under the ration which they were selected. However, as a proportion of initial BW the lines were closer in the amount of response seen (49 vs 37 %). Carcass data showed that selection under limited feed increased the growth rate of both fat and protein (McPhee et al., 1980). The period over which these mice were selected (5-9 weeks) was past the period of most rapid growth; however, selection was still successful when variation in appetite was eliminated. They concluded that a reduction in maintenance requirements is a likely reason for the increased growth rate.

One study in rats compared selection for rapid gain from 3 to 9 weeks on three diets: full feed (FF), limited to 75 % of full (LF) or limited protein (LP) (Park et al., 1966). Selection under FF and LF was effective in increasing growth on all three feeding conditions. However, response was higher in the FF as compared to the LF line when fed either limited protein or full feed. Response was similar in both lines when fed the limited diet. Little genetic gain was seen in the LP line and selection was only successful when fed the diet under which they were selected. Estimates of heritability for gain were lower in the LF line than the FF line.

<u>Response in Swine</u>

Only one study has been reported on selection for postweaning gain in pigs under limited nutrition (Fowler and Ensminger, 1960). High and low (70 % of high) nutrition lines were selected on an index of number of pigs born, number of pigs weaned and ADG from weaning to 68 kg. Selection for gain was effective in both lines. In the high line, absolute response per generation was higher, while on a percentage basis response was higher in the low line. After six generations half of each line remained on the diet which they were selected under, while the other half was switched to the opposite diet. These groups were designated as HH, HL, LH and LL, where the first letter designates diet under which they were selected and the second letter the diet which they were fed. Average daily gain was .69, .41, .68 and .45 for the HH, HL, LH and LL respectively. Pigs from the LH group were more efficient than HH pigs, suggesting that selection under limited nutrition lowered the metabolic rate and decreased fat deposition. However, no fat measurements were taken. Most of the superiority of the high line appears to be due to increased appetite. In agreement with what was reported in rats (Park et al., 1966), estimates of heritability for gain were lower in low-line than high-line pigs. It was concluded that selection for rapid growth under full and limited nutrition selects for two different traits.

Several articles have theorized the effects of selection under limited nutrition (Fowler et al., 1976; Smith and Fowler, 1978; Bichard et al., 1979; Whittemore, 1979). One of the main criticisms of selection under ad libitum feeding is that it allows for variation in feed intake. Thus genetic improvement in feed conversion and lean percent may be a result of selection for increased appetite (Smith and Fowler, 1978). In a nutritionally limited environment there is a positive relationship between increased feed intake and increased lean gain (Whittemore, 1979). Under limited nutritional environments, selection pressure would be on an increased ratio of lean to fat. In a nutritionally unlimited environment an increase in feed intake will result in an increase in fat deposition (Whittemore, 1979). In this case, selection against fat may either be for faster lean growth or decreased appetite. If appetite exceeds the need for lean tissue growth then fat will be deposited. As the potential for lean tissue growth increases the level of intake at which fattening occurs will also increase.

In trials involving semi-ad libitum feeding (twice daily for 20-30 min), complete carcass separation was used to estimate lean tissue growth rate (LTGR) (Fowler et al., 1976). It was concluded that most of the pigs were eating enough to express their potential for LTGR, suggesting that ad libitum feeding is not needed for full expression of this trait. Feed intake was also found to be unfavorably related to feed conversion ($r = .35$). During early stages of growth (< 35 kg) pigs should be fed near ad libitum, so sufficient feed is consumed to allow pigs to display their full ability for maximum LTGR (Bichard et al., 1979).

<u>Summary of Selection Under Limited Nutrition</u>

Selection under ad libitum diets allows for variation in appetite, meaning improvement in lean gain and feed efficiency may be due to increases in intake. Selection for growth when variation in appetite was eliminated was successful in all studies; however, less response was seen when selecting under limited conditions. Improvement in efficiency and a decrease in fat were seen in lines selected on limited diets and fed ad libitum. In pigs selected under full and limited diets and fed ad libitum, both lines had similar gains and the limited line was more efficient. Estimates of heritability were lower in lines selected under limited nutrition, which was also found to be true in rats. It appears that pig fed semi-ad libitum consumed enough to display their full potential for LTGR; however, pigs should be fed at or near ad libitum during early growth to allow for full expression of LTGR.

## Selection for Feed Efficiency

### Response in Swine

Selection for feed utilization has shown limited success in swine. Dickerson and Grimes (1947) selected lines of Duroc swine for either high or low feed requirements from 72 days of age through 102 kg. Daily gain was higher and F/G was lower in the superior line. However, it was concluded that selection for gain would be nearly as effective as direct selection in improving feed efficiency based on a high negative correlation between feed required per gain and ADG. The same conclusion was drawn by Jungst et al. (1981), where an improvement of .1 kg of feed/kg of gain was seen after five generations of selection in Yorkshire boars. No differences were seen between the select and control lines for either daily gain or backfat. Only a 2.5 % improvement in feed efficiency was seen after 10 generations of selection (Bernard and Fahmy, 1970). Selection was on pen basis, with four littermate boars tested per pen.

No significant difference in feed conversion ratio (FCR) were seen after six generations (Webb and King, 1983). Boars were tested individually or in pairs, while gilts were tested as littermate groups.

Response in the seventh generation was measured under both ad libitum and 77 % of ad libitum. Pigs selected for improved feed conversion had more fat than controls under both feeding regimes and FCR was negatively correlated with backfat. Level of nutrition did not affect the FCR.

Reviews in Swine

In reviewing the genetic aspects of feed efficiency in swine, Yuksel (1979) drew the following general conclusions:

1) Feed efficiency is favorably correlated with growth rate.
2) Selection for feed efficiency may not always reduce fat.
3) Efficiency and level of intake are negatively correlated.
4) Variation in efficiency may be caused by varying levels of protein and energy.
5) Selection for gain under restricted conditions should improve efficiency.

Prediction equations and indices to estimate lean growth have been discussed by Bereskin and Steele (1986). These authors noted that future emphasis should be placed on efficiency of lean growth rather than gross efficiency.

Response in Mice

Yuksel et al. (1981) selected four lines for efficiency over one of two age intervals (3 to 5 weeks or 5 to 7 weeks) and two feeding regimes (ad libitum or a fixed scale) for seven generations. Improvement in feed efficiency was seen in both age intervals, with a larger absolute gain in efficiency seen in the lines selected from 3 to 5 weeks and a larger percentage gain in the other lines. An improvement in gain was seen in all four lines. In the ad libitum lines all of the weight gain was due to improved efficiency, since there was no change in intake. Feed efficiency was similar in the lines selected under the two feeding regimes and testing under the alternative method showed no differences. Carcass data showed all lines increased in percent fat; however, those selected from 3 to 5 weeks deposited more fat. It was noted that selection over a fixed age may not be directly comparable to selection over a fixed BW range, as is seen in pigs. Estimates of heritability suggest improvement in feed efficiency may be as large or larger by direct selection for gain, as compared to direct selection for feed efficiency. Similar conclusions were drawn by Gunsett et al. (1981) when comparing lines selected for maximum gain under a fixed amount of feed (FF), minimum feed intake over a fixed gain (FG) and a control line. Both select lines consumed less per fixed gain and gained more per fixed amount of feed. High correlations for both FG and FF with 56-day weight suggests feed efficiency could be improved by selecting for increased 56-day weight.

## Reviews in Mice and Rats

In general, when mice were selected for efficiency or growth the improvement seen was in gross efficiency, with very little differences seen in net efficiency of tissue growth (Sutherland et al., 1974). In his review of feed efficiency in rats Yuksel (1979) concluded the following:

1) Gain and efficiency are favorably correlated.

2) The correlation of efficiency and intake is near zero.

3) Selection for efficiency may increase or decrease fat.

4) Improvement in efficiency may come about by reducing maintenance, increasing absorption or both.

In mice, the general conclusions were somewhat different from either rats or swine. They were as follows

1) Gain and efficiency are favorably correlated.

2) Selection for efficiency may increase, decrease or not effect consumption.

3) There is a small, but positive correlation between efficiency and carcass fat.

4) Efficiency improves when selecting for large body size, but there is no change when selecting for small size.

5) Selecting for either increased growth or decreased F/G does not generally alter maintenance requirements.

Summary of Selection for Efficiency

The majority of studies have concluded that direct selection for gain may result in changes in efficiency that are as large or larger than direct selection, even though response to selection for feed efficiency has been positive in both mice and swine. Yuksel (1979) reviewed feed efficiency in mice, rats and swine. The reviews of all three species are in agreement that feed efficiency and gain are favorably correlated; however, there are a number of species differences in response to selection for efficiency.

## Selection for Backfat Thickness in Swine

### Direct Response

Lines of Duroc and Yorkshire pigs were selected for high or low fat thickness (Hetzer and Harvey, 1967), with a control line of each breed maintained. After 10 generations of selection the high and low Duroc lines had diverged by 2.6 cm, with most of the difference occurring in the first five generations. After eight generations the Yorkshire lines differed by 1.4 cm. A number of other authors have reported on these lines (Davey et al., 1969; Hetzer and Miller, 1972; Hetzer and Miller, 1973; Bereskin and Davey, 1976; Steele and Frobish, 1976; Davey and Bereskin, 1978; Tess et al., 1986).

Spring and fall replicates of Poland Chinas were selected five generations for low backfat thickness (Gray et al., 1968). Probes were taken at the shoulder, last rib and last lumbar vertebrae and adjusted to 79.4 kg. A decrease in 5.5 mm and 6.2 mm was seen in the spring and fall lines respectively, with most of the response seen in the first two generations. It should be noted that no control lines were maintained. High genetic correlations were found between the three sites, suggesting many of the same genes control the deposition of backfat at all three sites. Selection was also effective in decreasing backfat in a composite line of Minnesota #1, Tamworth and Duroc breeds (Berruecos et al., 1970). Selection was based on two probes (seventh rib and middle of the loin) and adjusted to 63.6 kg. Response per generation, estimated by regressing the deviation from the control on generation number, was -0.65 mm per generation. An additional line selected for minimum backfat at market weight will be discussed in a later section, as compared to an index line selected for increased gain and decreased backfat (Sather and Fredeen, 1978; Fredeen and Mikami, 1986b).

Correlated Response in Performance Traits

Pigs selected for high fat thickness consume more food, are less efficient and gain essentially the same amount as pigs selected for low fat thickness (Bereskin et al., 1975). Yorkshire and Duroc breeds responded differently to selection for increased or decreased backfat (Hetzer and Miller, 1972). Correlated responses in growth traits were also different between the lines. It was concluded that there are breed differences in the way backfat is genetically correlated with growth traits. Growth rate increased with selection for decreased backfat in Duroc swine; however, in Yorkshires a reduction in growth rate accompanied downward selection for backfat. Small, nonsignificant decreases were seen in birth weight and 130-day weight in a line selected for decreased backfat (Berruecos et al., 1970). There was a correlated decrease of 1.01 kg per generation in 56-day weight, along with a decrease in litter size at birth and weaning.

Correlated Response in Carcass Traits

As would be expected, Duroc and Yorkshire lines selected for high carcass fat had a lower percent lean cuts, higher percent total fat and smaller loin eye areas (Hetzer and Miller, 1973). It appears that carcass traits are more highly correlated with selection for backfat thickness than growth traits. Divergence in fat depth between the Duroc and Yorkshire lines was 76 and 83 %, respectively. Growth coefficients for backfat between high and low fat lines did not differ relative to empty-body weight; however, high-fat pigs deposited more of their total fat as backfat (Tess et al., 1986). This suggests that selection for high and low backfat may alter the distribution of adipose tissue within the body. In comparing lean and obese pigs at 3 days and 8 weeks of age, obese pigs had significantly more fat as a percent of whole body tissue at 3 days (3.3 vs 2.2 %) and 8 weeks (13.6 vs 7.7 %) (Cote and Wangsness, 1978). Low-fat lines had a much higher efficiency of lean gain, defined as lean gain per dietary protein intake (Bereskin and Davey, 1976).

## Response to Nutritional Differences

No real differences were detected in feeding two levels of protein and energy to high- and low-fat Duroc and Yorkshire lines (Bereskin and Davey, 1976; Davey and Bereskin, 1978). The same lines were used to study the effects of ad libitum vs a limited (75 % of ad libitum) diet (Davey et al., 1969). Littermate pairs were slaughtered at intervals from 84 to 392 days. In all breed-line combinations the restricted diet increased the age at which fat gain exceeded lean gain, as well reducing fat tissue to a much greater degree (34 %) than lean tissue (7 %). Another study (Steele and Frobish, 1976) compared the same lines on ad libitum vs meal feeding and two energy levels. Pigs fed the higher energy diet and those on ad libitum diets gained faster; however, meal feeding decreased gain more in the low-fat line. They concluded that genotype was the major factor regulating lipogenic activity, rather than dietary manipulation.

Summary of Selection for Backfat

Selection for increased and decreased backfat has been successful in a number of lines. High genetic correlations have been found between various probed sites, suggesting selection at one site should change backfat at nearly the same rate at other sites. It appears there are breed differences in direct and correlated response to selection for backfat. Generally, pigs selected for low fat are more efficient and similar in postweaning gain, as compared to high-fat lines. The carcasses of high-fat pigs are less desirable and it appears that selection for backfat is more highly correlated with carcass traits, as compared to growth traits. There is some evidence that indicates that selection for backfat may alter the distribution of adipose tissue.

## Direct Comparison of Single Trait Selection Methods

Lines of mice have been selected for improved feed efficiency, increased appetite or increased gain from 28 to 77 d (Biondini et al., 1968; Sutherland et al., 1970). In addition a control line was maintained. The line selected for efficiency showed no change in gain, while gain increased in the other two select lines (Biondini et al., 1968). The largest increase in appetite was in the line selected for appetite (Sutherland et al., 1970). Similar increases in appetite were seen in the other two lines, with a slightly higher increase in the efficiency line. Improvement in efficiency was about twice as high per generation (.0031 vs .0013 gain/feed) in the efficiency line as in the gain line. Very little improvement in efficiency was seen in the appetite line (.0006 gain/feed).

A more recent study compared upward and downward single trait selection for appetite (A), fat (F) and protein mass (P) from 4 to 6 weeks of age (Sharp et al., 1984). The F line was selected on a ratio of gonadal fat to BW and the P line was selected on an index of BW and gonadal fat. Selection in the F and P lines was on carcass data collected in males after mating at 8 weeks. Respective upward and downward divergence in the selected traits after 11 generations was 8.0 and 8.6 % for the A line, 36.0 and 44.0 % for the F line and 26.7 and 13.0 % for the P line. In the P line, lows were fatter, while controls and highs were similar. The high P line displayed the most rapid gain.

In swine, a Canadian study looked at lines selected for decreased backfat, increased gain or an index of backfat and gain (Sather and Fredeen, 1978; Fredeen and Mikami, 1986a; Fredeen and Mikami, 1986b). However, no study designed to directly compare single-trait selection methods in swine was found.

## Index Selection

### Biological Indices

The biological index is an alternative approach to the classical economic index. It is an attempt to define the physiological changes which are desired to change the overall value of the pig as a meat producing animal (Fowler et al., 1976). Two indices of interest are lean tissue feed conversion (LTFC) and lean tissue growth rate (LTGR). Defined simply, LTFC is the amount of feed consumed per gain in lean tissue, while LTGR is the daily growth in lean tissue. These differ from the classical index in that in their simplest form LTFC or LTGR are selected for as a single trait, as opposed to combining all traits that make-up LTFC or LTGR into a weighted index.

There are a large number of components which compose LTFC, however the most important are deposition of fat, daily feed intake and lean tissue growth rate (Fowler et al., 1976). Utilizing different combinations of selection objectives and feeding regimes (ad libitum vs limit feed) can lead to divergent genotypes (Smith and Fowler, 1978). Selection for LTGR under ad libitum feeding should lead to large, fast-growing pigs with high daily intakes, while selection for LTFC under the same conditions should produce moderate-sized, lean pigs with a reduced appetite. A discussion on selection for LTGR and LTFC under limited nutrition was included in an earlier section on selection for postweaning gain under limited feed. One additional advantage of the biological index is that it may be a way of the avoiding the lack of good genetic parameters across environments (Fowler et al., 1976).

## Direct Selection for LTFC and LTGR in Rats

One laboratory looked at direct selection for LTGR and LTFC in rats (Notter et al., 1976; Wang et al., 1981). Between litter selection was practiced based on littermate slaughter data. Selection for LTGR was based on protein gain from 3 to 9 weeks, while selection for LTFC was based on protein gain per feed consumed over the same period. Selection was successful for LTFC and LTGR and both studies were in agreement that LTGR line rats were larger at maturity. Selection for LTGR resulted in larger gains from 3 to 9 weeks (Notter et al., 1976), more fat and less feed consumed (Wang et al., 1981), as compared to controls. In addition, Wang et al. (1981) reported LTFC line rats deposited less fat than LTGR or control lines, consumed less food than controls and were more fertile than LTGR line rats. Lean growth differences in the two lines were minor and maintenance requirements were lowered in both select lines (2 % for LTGR, 4 % for LTFC).

Swine Indices

Bernard and Fahmy (1970) were one of the earlier studies to report on a selection index. Selection was successful in improving both traits included in the index (feed utilization and carcass score), with response to selection for feed efficiency 48% higher than expected. No control line was included, however lines were included in which single-trait selection was practiced on the two traits included in the index. The genetic correlation between feed efficiency and carcass score was -.55, which may explain the large improvement in both traits.

Boars selected for 10 generations on an index of daily gain, feed efficiency and backfat were fed for a fixed time on a fixed intake (Henderson et al., 1983) and ad libitum (Ellis et al., 1983). As compared to a control line, the select line was more efficient and had a higher LTFC under both feeding regimes. Control boars fed ad libitum consumed more feed during the first 6 weeks of test, but the differences for the last 6 weeks and over the entire test were not significant. When on limited feed, the select line gained significantly more. However, there were no line differences in gain when under ad libitum conditions. It appears that the increase in LTFC was mainly accomplished through a decrease in intake, resulting in a decrease in backfat deposition.

Control boars had a significantly higher dressing percent when fed ad libitum, but there was no line differences for boars on fixed feed. Under both feeding regimes the select line had a larger proportion of lean tissue, a smaller percentage of fat and less subcutaneous fat. It does not appear that backfat was redistributed to other depots (Henderson et al., 1983; Wood et al., 1983). Carcass data were collected on boars at 27.6 kg (on-test weight) (Henderson et al., 1982). Select boars took 9 days more to reach this weight and had more lean and less fat than controls. Barrows and gilts from each line, slaughtered at 8 weights ranging from 15 to 120 kg, were not different in the amount of lean per kg of carcass (Wood et al., 1983). This indicates selection had a much larger effect on decreasing fat depth than increasing lean content.

In another study (McPhee et al., 1981) an index containing the same three traits was used to select from 45 to 80 kg, as compared to 27 to 87 kg in the previous study. Pigs were fed either ad libitum or restricted rations after an average of 4.3 generations of selection. A ration x line interaction was the result of select pigs gaining faster on restricted diets and control pigs gaining faster on full feed. Select pigs were more efficient than controls on both rations, while pigs fed limited diets were more efficient than those fed ad libitum. The LTFC was 7.5 and 5.8 % higher in the select line for ad libitum and restricted diets, respectively. The LTGR was 5% higher in the select line fed the restricted diet; however, there was very little difference between lines on full feed. Carcass data indicates that select pigs were more lean, but there were no differences in loin eye area. This study is in agreement with Henderson et al. (1983) and Wood et al. (1983), in that selection reduced feed intake and backfat with very little change in daily gain.

A Norwegian study (Vangen, 1974) compared upward and downward response to selection on an index of gain and backfat. An unselected control line was maintained. The line selected for increased gain and decreased backfat (HP) improved in both traits included in the index and had an improved FCR. Response for all three traits in the downward line (LP), selected for increased backfat and decreased gain, was opposite that seen in the HP line.

The index equally combined growth and backfat by weighting each trait according to their standard deviation (SD) (Vangen, 1979). Response in average index score was much larger in the LP line. Most of this difference was due to backfat, where the magnitude of response was over three times higher in the LP line than the HP line. This difference can be attributed to higher selection differential and a low estimate of the SD for backfat, resulting in increased selection pressure on backfat.

Data representing about seven generations of selection were used to regress body weight, daily gain, feed consumption and FCR on age (Vangen, 1977). Pens of littermates were fed from weaning through 90 kg. All regressions were significantly different from zero. The only line difference for slope was body weight on age, where the HP line was the steeper and the LP the gentlest. Feed consumption and daily gain leveled off near the end of test in the HP and control lines, while the LP line continued to increase. The only trait to change rank was FCR where LP pigs were more efficient early and HP pigs were more efficient past 120 days of age.

Regression of daily gain, feed consumption and FCR on weight indicated a quadratic response for daily gain and feed consumption, while FCR was best described by a linear fit (Vangen, 1977). A very pronounced difference in daily gain was seen over the last 15 kg. Over this period the control and LP lines started to decrease and the HP line continued to increase. Differences in daily gain and consumption were greater in the period up to 55 kg, as compared to the finishing period. However, differences in FCR were greatest over the later period.

Carcass data on the HP and LP lines indicates that after four generations of selection the lines were divergent in percent fat and muscle (Standal et al., 1973). Percent muscle was 46.0, 48.1 and 52.0, while percent fat was 30.0, 25.3 and 21.5 for the LP, control and HP lines, respectively. Very small differences were seen in eye muscle area of the three lines, while a slight decrease per generation was seen in the meat color score of the HP line (Vangen et al., 1980a). Percent ham and loin increased in the HP line and decreased in the LP line. It was suggested that LTFC and LTGR of the HP line had increased over the controls.

Maintenance differences between the two lines were estimated by individually feeding pigs from both lines at the same intake level (Vangen, 1980b). They were fed at a level near expected maintenance. The HP line had lower maintenance requirements and it was suggested that this is due to less energy required to maintain the higher lean content of the HP line.

A Canadian study (Sather and Fredeen, 1978) selected for an index of increased postweaning gain and decreased backfat. The index was based on the phenotypic SD for each trait, as was the index previously discussed. The two traits in the index along with feed efficiency were improved. The largest improvement in standard deviation units was detected in backfat. More improvement was seen in efficiency than gain, even though gain was selected for directly. Using economic values, a substantial increase in potential profitability was calculated. The index line was directly compared to single trait selection lines for gain (G) and backfat (B) (Fredeen and Mikami, 1986b). The G line was about 15 % fatter, but very similar in gain. The B line gained 10 % less and had 6.5 % more lean than the index line. Carcass data indicated a 10% advantage for the index line over the controls for percent dissected lean (50.7 vs 46.1 %) (Fredeen and Mikami, 1986a). Loin eye area was larger in the index and B lines, while very little difference was seen between the control and G lines. Subjective meat quality scores indicated no harmful effects were correlated with selection.

A third study looked at selection on an index of postweaning gain and backfat (Cleveland et al., 1982). The index used in this study differed from the previous two studies, in that it was derived from economic weighting and genotypic and phenotypic statistics. More emphasis was placed on ADG in this experiment as compared to the study by Vangen (1979). Response per generation was .014 kg,. -.045 cm and 5.76 points for ADG, backfat and the index, respectively (Cleveland et al., 1982). Realized response was 41 and 38 % of expected for ADG and backfat, respectively, which may be due in part to inappropriate genetic statistics and/or experimental conditions.

Barrows were fed at three levels of intake: ad libitum (AL), 91 % of ad libitum (AL91) and 82 % of ad libitum (AL82) (Cleveland et al., 1983). Daily gain was 9 % higher in select-line barrows fed the AL and AL91 levels and 5 % higher in barrows fed the low level of intake, as compared to controls. Differences in protein gain were small between the AL and AL91 groups; however, a there was a significant drop in protein gain in the AL82 group. Protein gain decreased 20 and 13 % between the AL and AL82 intake levels, respectively, for the index and control lines. It should be noted that feed restriction in these lines was started near 25 kg, below the weight suggested by Bichard et al. (1979) to allow for pigs to display their full potential for LTGR. Also, daily protein intake of the AL82 was only 88 and 93 % of required for the select and control lines, respectively.

An additional study selected for indices that increased percent lean cuts at 81.6 kg (PCLC) or weight of lean cuts at 160 days (WLC) (Leymaster et al, 1979). Response after four generations was .50 kg/generation in the WLC line and .38 %/generation in the PCLC line. Average backfat decreased 14 % in the PCLC line and 3 % in the WLC line, as compared to controls (DeNise et al, 1983).

Summary of Indices

An alternative to the classical index is the biological index. Two biological indices of importance are LTFC and LTGR. A comparison in rats of lines selected for LTFC or LTGR indicated LTFC lines were more lean. Feed consumption decreased in both lines, differences in lean growth were minor and both selected lines had slightly lowered maintenance requirements.

Pigs selected for an index of gain, efficiency and backfat were more efficient, both on a gross and net (LTFC) basis, when fed either ad libitum or restricted diets. Select pigs gained faster than control when both were fed limited diets; however, when fed ad libitum there was either no difference or control-line pigs gained faster. The decreased gain in select pigs is a result of a correlated decrease in intake. This decrease in intake results in less deposition in fat, thus an increase in LTFC. On full feed no differences were seen in LTGR, while the select line had a higher LTGR when fed a restricted diet. Select pigs had a lower proportion of fat and more lean near 30 kg and market weight. This increase in the proportion of lean is mainly the result of a decrease in fat depth.

Three studies compared an index of gain and backfat. Improvement was seen in the two traits included in the index, as well as in feed efficiency. The relative amounts of improvement in the two traits varied between the studies, which was partially due to difference in the way the indices were constructed. Line differences for daily gain and intake were largest during the growing period, while differences in efficiency were greater during the finishing period. However, the regression of daily gain on weight indicates a large difference in gain over the last 15 kg of the finishing period. Single-trait selection for either gain or backfat improved only the trait selected for, while an unfavorable response was seen in the other trait.

## Effects of Limit Feeding in the Pig

Limit feeding was reviewed prior to 1956 (Lucas and Calder, 1956) and from 1956 to 1967 (Vanschoubroek et al., 1967). Some of the conclusions of Lucas and Calder were: that there is lack of agreement on whether restricted nutrition improves feed efficiency, there are interactions of pig type and level of nutrition and the benefits of small amounts of feed restriction can be surpassed by small amounts of genetic improvement. By combining previous studies, Vanschoubroek et al. (1967) found that feed restriction of 15.8 % results in 12.5 % decrease in daily gain, about 4 % improvement in efficiency and a 7.63 % decrease in backfat. As the restriction becomes more severe the decrease in gain becomes greater and the decrease in backfat relatively smaller. An improvement in efficiency is seen up to about 25 % restriction.

A number of studies have been done since 1967 looking at the effects of limit feeding. No difference in efficiency was seen between pigs fed ad libitum versus restricted (82 % of ad libitum) from 20 to 95 kg, but limit-fed pigs were on feed 18 d longer (Stahly and Wahlstrom, 1973). Just and Pedersen (1976) suggested lean tissue formation will only be slightly affected, provided energy and essential nutrient requirements are met, while fat deposition increases with feeding intensity. Pigs fed ad libitum or restricted to 80 % of ad libitum intake were slaughtered at weights ranging from 30 to 110 kg (Metz et al., 1980). Feed restriction reduced gain by 20 %, improved LTFC by 15 %, decreased fat deposition by 28 % and protein deposition by 8 %, while having no effect on the proportion of bone. Pigs fed near ad libitum versus those restricted to 57 % tended to develop less cavity and intermuscular fat and more subcutaneous fat (Davies et al., 1980). This leads to a possible overestimation of fat content in carcasses of pigs reared under full versus limited nutritional environments.

Gain was found to decrease in a linear fashion when feeding progressively limited levels of nutrition (Malynicz, 1974; Fuller and Livingstone, 1978; Giles et al., 1981). The most efficient level of restriction was near 75 %, with large decreases occurring at severely restricted levels (Fuller and Livingstone, 1978; Malynicz, 1974). Fat gain increased linearly with level of intake, while lean gain leveled off at higher intake levels (Fuller and Livingstone, 1978). The previous authors also found gilts to be superior to barrows at low levels of nutrition, with this advantage disappearing as intake increased.

The effects of breed (Duroc x Yorkshire, Hampshire x Yorkshire and Yorkshire) and energy level (high versus low) on carcasses were examined (Richmond and Berg, 1971abc). A similar study examined the effects of breed type (different breeding companies) and nutritional environment (limited versus ad libitum) on carcass composition (Evans and Kempster, 1979; Kempster and Evans, 1979). Pigs fed high energy diets were more efficient, had a higher percent fat and a lower percent lean (Richmond and Berg, 1971c). Plane of nutrition did not affect the distribution of muscle to much degree (Richmond and Berg, 1971b), however from data of Kempster and Evans (1979) it appears limit feeding may cause a redistribution of lean and fat tissue. Ad libitum pigs had more lean in the loin, ribs and belly and less in the ham and foreleg. At an equal weight of total fat, ad libitum pigs had more flare fat and less subcutaneous fat. Thus probed backfat measurements may lead to an underestimation of total fat in pigs fed restricted diets, which is in agreement with Davies et al. (1980), as discussed earlier. Correlations between backfat measurements and intermuscular fat were near .40, suggesting that selection for decreased backfat may not change intermuscular fat nearly as rapid as subcutaneous fat (Richmond and Berg, 1971a).

### Summary of Limit Feeding

Feed restriction of less then 25 % improves feed efficiency and decreases fat deposition with little effect on the formation of lean tissue. Gain decreases in a linear fashion with increasing levels of restriction. Limit feeding may cause redistribution of lean and fat, thus probed backfat measurements may lead to underestimation of total fat in pigs fed limited diets.

## Growth Curve Analysis

Growth curves have been reviewed in swine (Robison, 1976) and mice and rats (Eisen, 1976). Postnatal growth patterns in mice and rats generally follow a sigmoid shape. In swine, Robison concluded that the quadratic term of postweaning growth curves is of statistical significance, but is probably of very little practical importance. In general, the relationship of backfat or protein gain in the carcass with either weight or age is nearly linear.

Early, non-statistical work showed growth to be essentially linear from birth to about 72.6 kg, at which time growth rate slowed (Ittner and Hughes, 1938). Based on weights from 134 to 174 d of age, growth rate was found to be linear (Taylor and Hazel, 1955). Shapes of the curves were very similar for the fastest and slowest growing thirds of the group of pigs studied. Donald (1940) looked at two groups of pigs with different potential for growth. He found significant quadratic terms for both groups, with the faster growing pigs having a steeper curve that leveled off more quickly at the top. The growth curve of Duroc swine to near 1 year of age was found to be curvilinear in its shape (Abarca and Tapia, 1963). A more recent study looked at weight and backfat curves in lines of Duroc swine and Yorkshires (Quijandria and Robison, 1971). Linear effects were significant for all regressions across both breeds; however, significant quadratic effects were not consistent across breeds. They concluded growth curves are influenced by the genotype of the animal and environment.

Doornenbal (1971, 1972) collected carcass data on pigs over a range of 10 to 132 kg. Daily protein gain increased in a linear fashion. However, when protein was expressed as a percent of empty body wt there was a gradual decrease (16 % at 10 kg, 13 % at 130 kg). Over this same period of time fat gain also increased in a linear fashion, with percent fat increasing from 13.8 to 42.2 %. During the entire period, daily fat gain did not exceed daily protein gain, however fat gain was increasing at a faster rate. Protein gain increased in each of the four major wholesale cuts (ham, loin, shoulder and belly); however, the rate of increase was lower in the belly. The rate of carcass fat gain was similar for each of the major cuts except the loin where fat gain was about twice as high. Overall fat increased as a percent of total carcass in the loin and belly and decreased in the ham and shoulder. One additional study found live and empty-body weight increased linearly from 18 to 145 kg (Shields et al., 1983). Protein and water weight increased at a decreasing rate, while fat increased at an increasing rate

## Physiological Response to Selection

### Mice

Mice selected for large size were more active than those selected for small size; however, activity did not appear to determine growth rate (Fowler, 1962). Large mice absorbed more protein through their digestive system (5 %), but this difference was not large enough to account for all of the weight difference between the two lines.

Mice absent of growth hormone were produced by transferring a dwarf gene into large and small strains of mice by repeated backcrosses (Pidduck and Falconer, 1978). The dwarf gene causes the production of little or no growth hormone. Growth of the large line was lowered; however, the relative difference in growth remained. This indicates growth hormone plays some intermediate role in increasing growth rate in the mouse. In addition, less response in relative growth rate was seen in the small line as levels of exogenous GH were increased. The authors concluded that selection for large size increased circulating growth hormone (GH), while selection for small size decreased the sensitivity of target organs to the hormone. Stephenson and Malik (1984) suggested an alteration of the growth hormone-insulin balance caused low mice to gain relatively more protein and less fat.

Levels of plasma thyroxine (T4) were significantly higher in large mice as compared to control or small lines (Cartwright et al., 1980).

No differences were seen in plasma triiodothyronine (T3) levels. This difference may be due to selection altering tissue sensitivity or tissue capacity to metabolize thyroid hormones.

The effect of selection for increased and decreased size or growth on maintenance levels were discussed in an earlier section.

Swine

Early work in this area was done on lines of Hampshire pigs selected for either rapid- or slow-postweaning gain (Baird et al., 1952). The two lines had diverged by 28 kg at 180 days of age. Pituitary and thyroid weight and pituitary growth hormone were compared at 56, 75, 115, 154 days and maturity. Weights of each gland in the rapid line were heavier at all ages; however, there were no differences when compared as a percent of body weight. Higher amounts of GH were found in the rapid line at all weights, except 56 days of age. In relation to anterior pituitary size, GH increased up to 115 days in the rapid line and then decreased. In the slow line this peak was reached at day 75 and maintained through day 154. Landrace pigs selected for high 200-day weight, as reported by Kuhlers and Jungst (1986), have greater baseline level of GH (Arbona et al., 1986). After three generations of selection barrows from the high weight line had a higher percent lean cuts than control pigs.

A large number of physiological studies have been done on the Norwegian index lines discussed previously (Standal et al., 1973; Vangen, 1974; Vangen, 1977; Vangen, 1979; Vangen, 1980ab). In vitro examination of lipid mobilization showed release of non-esterfied fatty acids (NEFA) was highest in LP-line pigs and lowest in the HP line

(Standal et al., 1973), indicating selection has resulted in divergence in the inhibition of lipolysis. Levels of serum NEFA and glucose were examined in 5-month-old pigs at 1 to 2 h after feeding, 25 to 26 h fasting and 28 to 29 h fasting (Bakke, 1975). No differences were found immediately after feeding. However, after fasting HP pigs had significantly higher levels of NEFA and lower levels of glucose. In a separate trial, no differences were found when 90- and 140-day-old pigs were bled after 21 h fasting.

Work done after additional generations of selection indicates HP pigs have a much higher ability to mobilize stored fat (Standal and Vangen, 1980). A number of other differences were found between the lines, including higher levels of serum cholesterol, somatomedins and GH in the HP line. The LP line had higher levels of serum triglycerides, with no line differences seen in T3 or T4 degradation. Concentrations of T3 and T4 were not significantly correlated with either growth rate or feed conversion from blood samples taken at 20, 40 and 60 kg (Bakke and Tveit, 1977). One of the largest effects of thyroid hormones is to increase the rate of energy metabolism. Levels of thyroid activity tended to be higher in the HP line, though the differences were non-significant (Standal et al., 1980). From the levels of thyroid hormones found it appears that only some part of the difference in gain and backfat between the lines was due to thyroid activity.

As compared to the LP line, HP-line pigs produce more heat and require about 22 % more energy to maintain a zero energy balance (Sundstol et al., 1979). Selection for increased 200-day weight in Landrace pigs also increased the energy requirement (Prince et al., 1986).

The ratio of protein to DNA was lowered in HP-line pigs, as compared to the LP line (Lundtrom et al., 1983). Total cortisol and corticosteroid binding globulin (CBG) concentrations were lowered in HP-line pigs. This in part may explain some of the differences in growth and backfat between the two lines. The effect of cortisol is a net loss of amino acids and a decrease in amino acid incorporation, making more amino acids available to the liver. This will contribute to increased gluconeogenesis, causing an elevation of insulin, which in turn stimulates lipogenesis and contributes to obesity. Also, the excess in amino acids from the higher protein/DNA in the LP-line pigs may contribute to obesity.

Concentrations of GH were compared in Duroc and Yorkshire lines selected for high and low backfat (Althen and Gerrits, 1976). These lines have been discussed earlier (Hetzer and Harvey, 1967), having well over a twofold divergence in backfat thickness. Serum GH levels were lower in high-fat lines at 8 weeks, while at 95 kg high-fat lines of both breeds had smaller pituitaries and lower levels of pituitary GH. Serum GH did not differ in Yorkshires, while it was lower in the high-fat Duroc swine. Another series of studies compared a line of lean Yorkshires with a line of obese Ossabaw pigs (Wangsness et al., 1977; Buhlinger et al., 1978; Wangsness et al., 1980). These differed from the previous lines in that the growth rate was much more divergent; the lean line was twice as heavy at five months. Fasting levels of glucose did not differ at 1, 3 or 6 mo, while fasting GH was higher in the lean pigs (Wangsness et al., 1977). Obese pigs were less tolerant to glucose infusion, indicating a mild resistant to insulin at both 3 and 6 mo. Muscle RNA and DNA was greater in lean pigs at either equal weight or equal age. The lower DNA levels in the obese line may be a result of lowered GH production, as reported by Wangsness et al. (1977). Fasting levels of insulin and glucose did not differ between lines, however free fatty acid concentration was higher in obese pigs (Wangsness et al., 1980). Infusion of insulin resulted in a higher GH peak in the lean strain.

### Summary of Physiological Responses

The physiological basis for differences in growth rate or backfat thickness is complex and a number of differences have been found. Increased levels of GH have been found in mice and pigs selected for increased growth. Pituitary GH levels were lower in high-fat lines at 8 weeks and 95 kg, while breed differences occurred in serum GH levels. Thyroid hormones appear to play some role in differences between lines. Other substances which have been examined include NEFA, serum glucose, serum cholesterol, somatomedins, cortisol and CBG. The ratio of protein to DNA was lower in LP-line pigs, while muscle DNA and RNA was higher in fast-growing, lean pigs at either equal weights or ages.

## Review of the Lines Examined in this Study

After two generations of selection rapid growth line (RGL) pigs grew faster, were fatter, had a higher daily intake and were more efficient; as compared to slow growth line (SGL) pigs (Buchanan et al., 1984). In addition, RGL pigs also tended to be heavier at birth and 42 days of age. Evaluation of front-end soundness after four generations of divergent selection in a fall replicate and five generations in a spring replicate indicated no difference in soundness between the lines

(Woltmann et al., 1987). However, there was a line x replicate interaction, with the RGL being more sound in the spring and the SGL more sound in the fall. The difference in ADG from 9 weeks of age through 100 kg was about .13 kg/day after four generations of divergent selection (Clutter et al., 1988). The difference in gain was much greater in the finishing phase (54.4 to 100 kg), as compared to the growing phase (9 weeks of age through 54.4 kg), .17 vs .09 kg/day, respectively. However, no consistent difference was seen in the reproductive performance of the two lines.

Differences in response to nutritional treatments have been reported. In a comparison of corn and wheat based diets, SGL pigs grew 4.4 % faster on wheat and RGL grew 2% faster on corn during the growing period (Maxwell et al., 1985a). During the finishing period no differences were seen in the RGL, while SGL pigs gained 6.6 % faster on corn. The effect of three diets; wheat-soybean meal (WSB), wheat-lysine (WL) and wheat-lysine plus threonine (WLT), were compared in both lines (Maxwell et al., 1985b). A larger drop in performance was seen during the growing period in the RGL than in the SGL fed WSB as compared to WL (22 vs 12.9 %). The SGL performed equally well on either WSB or WLT, while performance in the RGL was lower on the WLT, as compared to the WSB. This indicates threonine may be the first limiting amino acid for the SGL during the growing period. It was concluded the effects of threonine on GH release may differ between the two lines.

One study has examined the physiological differences of the two lines (Norton et al., 1986a; Norton et al., 1986b). Blood samples were taken at 20 min intervals for 12 h. Mean levels of GH were higher in the SGL (4.06 vs 3.17 ng/ml), while insulin and glucose levels were higher in the RGL (Norton et al., 1986a). Secretory patterns of GH were not significant over time in the SGL, while response in the RGL was described as an 8th order equation. Insulin peaked more over the interval in RGL (10 vs 5 peaks), while secretory patterns of glucose were linear in the SGL and cubic in the RGL. Although serum GH levels were not different when challenged with glucose, the RGL gilts secretory pattern was described by a 5th degree polynomial while SGL gilts showed no effect over time (Norton et al., 1986b). Insulin levels were higher in the RGL immediately following glucose challenge.

## Summary

Single-trait selection in swine for increased gain, decreased backfat and improved F/G has been successful in a number of studies. Ideally selection for one of the three traits would result in improvement of all three traits. This is not the case however, due to unfavorable correlations between traits. Selection for increased gain results in improved F/G and increased deposition of fat. Selection for F/G has been successful, but correlations between growth and efficiency suggest that direct selection for growth may result in similar improvements in efficiency. In addition, measuring F/G is impractical in most situations. Selection for decreased backfat appears to decrease ADG slightly, while it is favorably correlated with F/G.

Index selection should result in maximum overall improvement for the traits included. Selection for an index of ADG, F/G and backfat results in improved efficiency, decreased backfat and intake, with no appreciable change in growth under ad libitum conditions. When fed at the same limited level as controls the index line gained faster, which was a result of the improved F/G. Improvement was seen in both traits included in an index of ADG and backfat, along with a favorable response in F/G.

Selection for gain in swine under limited nutrition has only been reported in one study. Selection on a limited diet resulted in similar gains and an improved F/G when fed ad libitum, as compared to a line selected on full feed. In mice, fat decreased and efficiency improved when select lines were fed ad libitum. Further work is needed in this area, especially comparing selection for gain under limited nutrition to selection for gain or an index on full feed. Theoretically, selection pressure would be on an increased ratio of lean to fat. Selection under a limited diet should improve both LTFC and LTGR when response is measured on ad libitum diets.

## LITERATURE CITED


Abarca, V. and J. Tapia. 1963. Growth curve and correlations between weights at different ages in Duroc Jersey. Anim. Breed. Abstr. 34:455 (Abstr.).

Allen, P. and J. C. McCarthy. 1980. The effects of selection for high and low body weight on the proportion and distribution of fat in mice. Anim. Prod. 31:1.

Althen, T. G. and R. J. Gerrits. 1976. Pituitary and serum growth hormone levels in Duroc and Yorkshire swine genetically selected for high and low backfat. J. Anim. Sci. 42:1490.

Arbona, J. R., D. N. Marple, D. R. Mulvaney, J. S. Sartin, C. H. Rahe, T. J. Prince, D. L. Kuhlers and S. B. Jungst. 1986. Secretory patterns of growth hormone in swine selected for growth. J. Anim. Sci. 63(Suppl. 1): 201 (Abstr.).

Baird, D. M., A. V. Nalbondov and H. W. Horton. 1952. Some physiological causes of genetically different rates of growth in swine. J. Anim. Sci. 11:292.

Baker, D. L. and A. B. Chapman. 1975. Correlated responses to selection for postweaning gain in the rat. Genetics 80:191.

Bakke, H. 1975. Serum levels of non-esterfied fatty acids and glucose in lines of pigs selected for rate of gain and thickness of backfat. Acta Agric. Scand. 25:113.

Bakke, H. and B. Tveit. 1977. Serum levels of thyroid hormones in lines of pigs selected for rate of gain and thickness of backfat. Acta Agric. Scand. 27:41.

Bereskin, B. and R. J. Davey. 1976. Breed, line, sex, and diet effects and interactions in swine carcass traits. J. Anim. Sci. 42:43.

Bereskin, B., R. J. Davey, W. H. Peters and H. O. Hetzer. 1975. Genetic and environmental effects of interactions in swine growth and feed utilization. J. Anim. Sci. 40:53.

Bereskin, B. and N. C. Steele. 1986. Efficiency of feed utilization in swine: a review of research and current applications. USDA, ARS, Production Res. Report 184. Beltsville, MD.

Bernard, C. and M. H. Fahmy. 1970. Effect of selection on feed utilization and carcass score in swine. Can. J. Anim. Sci. 50:575.

Berruecos, J. M., E. V. Dillard and O. W. Robison. 1970. Selection for low backfat thickness in swine. J. Anim. Sci. 30:844.

Bichard, M., V. R. Fowler, C. T. Whittemore and A. N. P. Brown. 1979. Objectives: Growth, efficiency, and appetite; test regimes in selection for feed efficiency. European Pig Testing Conference, Harrogate, England.

Biondini, P. E., T. M. Sutherland and L. H. Haverland. 1968. Body composition of mice selected for rapid growth rate. J. Anim. Sci. 27:5.

Brown, M. A. and R. R. Frahm. 1975. Feed efficiency in mice selected for preweaning and postweaning growth. J. Anim. Sci. 41:1002.

Brown, M. A., R. R. Frahm and R. R. Johnson. 1977. Body composition of mice selected for preweaning and postweaning growth. J. Anim. Sci. 45:18.

Buchanan, D. S., D. G. McLaren, R. O. Bates and R. Vencl. 1984. Characteristics of rapid and slow growing lines of pigs. Okla. Agr. Exp. Sta. MP-116:1.

Buhlinger, C. A., P. J. Wangsness, R. J. Martin and J. H. Ziegler. 1978. Body composition, in vivo lipid metabolism and skeleton muscle characteristics in fast-growing, lean and in slow-growing, obese pigs at equal age and weight. Growth 42:225.

Canolty, N. L. and L. J. Koong. 1976. Utilization of energy for maintenance and for fat and lean gains by mice selected for rapid postweaning growth rate. J. Nutr. 106:1202.

Cartwright, A. L., J. M. Leatherwood and E. J. Eisen. 1980. Thyroid hormones and efficiency of energy utilization in mice selected for body weight. J. Nutr. 110:1262.

Cleveland, E. R., P. J. Cunningham and E. R. Peo. 1982. Selection for lean growth in swine. J. Anim. Sci. 54:719.

Cleveland, E. R., R. K. Johnson and R. W. Mandigo. 1983. Index selection and feed intake restriction in swine. I. Effect on rate and composition of growth. J. Anim. Sci. 56:560.

Clutter, A. C., M. D. Woltmann, D. S. Buchanan and R. Vencl. 1988. An evaluation of rapid versus slow growing lines of pigs. Okla. Agri. Exp. Sta. MP-125:10.

Cote, P. J. Jr. and P. J. Wangsness. 1978. Rate, composition and efficiency of growth in lean and obese pigs. J. Anim. Sci. 47:441.

Dalton, D. C. 1967. Selection for growth in mice on two diets. Anim. Prod. 9:425.

Davey, R. J. and B. Bereskin. 1978. Genetic and nutritional effects on carcass chemical composition and organ weights in market swine. J. Anim. Sci. 46:992.

Davey, R. J., D. P. Morgan and C. M. Kincaid. 1969. Response of swine selected for high and low fatness to a difference in dietary energy intake. J. Anim. Sci. 28:197.

Davies, A. S., G. Pearson and J. R. Carr. 1980. The carcass composition of male, castrated male and female pigs resulting from two levels of feeding. J. Agric. Sci. 95:251.

DeNise, R. S. K., K. M. Irvin, L. A. Swiger and R. F. Plimpton. 1983. Selection for increased leanness of Yorkshire swine. IV. Indirect responses of the carcass, breeding efficiency and preweaning litter traits. J. Anim. Sci. 56:551.

Dettmers, A. E., W. E. Rempel and R. E. Comstock. 1965. Selection for small size in swine. J. Anim. Sci. 24:216.

Dickerson, G. E. and J. C. Grimes. 1947. Effectiveness of selection for efficiency of gain in Duroc swine. J. Anim. Sci. 6:265.

Donald, H. P. 1940. Growth rate and carcass quality in bacon pigs. A study of polynomial coefficients fitted to growth rate data. J. Agric. Sci. 30:582.

Doornenbal, H. 1971. Growth, development and chemical composition of the pig. I. Lean tissue and protein. Growth 35:281.

Doornenbal, H. 1972. Growth, development and chemical composition. II. Fatty tissue and chemical fat. Growth 36:185.

Eisen, E. J. 1987. Effects of selection for rapid postweaning gain on maturing patterns of fat depots in mice. J. Anim. Sci. 64:133.

Eisen, E. J. 1976. Results of growth curve analysis in mice and rats. J. Anim. Sci. 42:1008.

Ellis, M., W. C. Smith, R. Henderson, C. T. Whittemore and R. Laird. 1983. Comparative performance and body composition of control and selection line Large White pigs. 2. Feeding to appetite for a fixed time. Anim. Prod. 36:407.

Evans, D. G. and A. J. Kempster. 1979. The effects of genotype, sex, and feeding regime on pig carcass development. 1. Primary components, tissues, and joints. J. Agric. Sci. 93:339.

Falconer, D. S. 1960. Selection of mice for growth on high and low planes of nutrition. Genet. Res. 1:91.

Fine, N. C. and L. M. Winters. 1953. Selection for an increase in growth rate and market score in two inbred lines of swine. J. Anim. Sci. 12:251.

Fowler, R. E. 1962. The efficiency of food utilization, digestibility of foodstuffs and energy expenditure of mice selected for large or small body size. Genet. Res. 3:51.

Fowler, R. E. 1958. The growth and carcass composition of strains of mice selected for large and small body size. J. Agric. Sci. 51:137.

Fowler, R. E. and M. E. Ensminger. 1960. Interaction between rate of gain and plane of nutrition in selection for rate of gain in swine. J. Anim. Sci. 19:434.

Fowler, V. R., M. Bichard and A. Pease. 1976. Objectives in pig breeding. Anim. Prod. 23:365.

Fredeen, H. T. and H. Mikami. 1986a. Mass selection in a pig population: Correlated changes in carcass merit. J. Anim. Sci. 62:1546.

Fredeen, H. T. and H. Mikami. 1986b. Mass selection in a pig population: Experimental design and responses to direct selection for rapid growth and minimum fat. J. Anim. Sci. 62:1492.

Fuller, M. F. and R. M. Livingstone. 1978. Effect of progressive feed restriction on the growth and carcass composition of pigs: comparative responses of gilts and castrates. J. Agric. Sci. 91:337.

Giles, L. R., R. D. Murison and B. R. Wilson. 1981. Backfat studies in growing pigs. I. Influence of energy intake on growth and carcass measurements at varying live weights. Anim. Prod. 32:39.

Gray, R. C., L. E. Tribble, B. N. Day and J. F. Lasley. 1968. Results of five generations of selection for low backfat thickness in swine. J. Anim. Sci. 27:331.

Gunsett, F. C., D. H. Baik, J. J. Rutledge and E. D. Hauser. 1981. Selection for feed conversion on efficiency and growth of mice. J. Anim. Sci. 52:1280.

Hayes, J. F. and J. C. McCarthy. 1976. The effect of selection at different ages for high and low body weight on the pattern of fat deposition mice. Genet. Res. 27:389.

Henderson, R., C. T. Whittemore, M. Ellis, W. C. Smith and R. Laird. 1982. Effects of index selection at bacon weight on early growth rate and body composition in Large White pigs. Anim. Prod. 35:81.

Henderson, R., C. T. Whittemore, M. Ellis, W. C. Smith, R. Laird and P. Phillips. 1983. Comparative performance and body composition of control and selected lines of Large White pigs. 1. On a generous fixed feeding scale for a fixed time. Anim. Prod. 36:399.

Hetzel, D. J. and E. W. Nicholas. 1982. Direct and correlated responses to selection for postweaning gain on ad libitum or restricted feeding in mice. Theor. Appl. Genet. 63:145.

Hetzer, H. O. and W. R. Harvey. 1967. Selection for high and low fatness in swine. J. Anim. Sci. 26:1244.

Hetzer, H. O. and R. H. Miller. 1972. Rate of growth as influenced by selection for high and low fatness in swine. J. Anim. Sci. 35:730.

Hetzer, H. O. and R. H. Miller. 1973. Selection for high and low fatness in swine: correlated responses of various carcass traits. J. Anim. Sci. 37:1289.

Ittner, V. R. and E. H. Hughes. 1938. A normal growth curve for swine. J. Hered. 29:385.

Jungst, S. B., L. L. Christian and D. L. Kuhlers. 1981. Response to selection for feed efficiency in individually fed Yorkshire boars. J. Anim. Sci. 53:323.

Jungst, S. B. and D. L. Kuhlers. 1987a. Correlated responses in reproduction after four generations of mass selection for growth to 70 days of age in Landrace pigs. J. Anim. Sci. 65(Suppl. 1):7 (Abstr.).

Jungst, S. B. and D. L. Kuhlers. 1987b. Four generations of mass selection for growth to 200 days in Duroc pigs. II. Carcass traits. J. Anim. Sci. 65(Suppl. 1):201 (Abstr.).

Just, A. and O. K. Pedersen. 1976. Danish investigations concerning body composition of pigs in relation to nutrition, sex, and slaughter weight. Livest. Prod. Sci. 3:271.

Kempster, A. J. and D. G. Evans. 1979. The effect of genotype, sex, and feeding regime on pig carcass development. 2. Tissue weight distribution and fat partition between depots. J. Agric. Sci. 93:349.

Kottman, R. M., J. L. Lush and L. N. Hazel. 1948. Selection in inbred lines of swine. J. Anim. Sci. 7:513 (Abstr.).

Kownacki, M., T. Jezierski, A. Guszkiewicz and A. Majewska. 1979. Effects of selection on the body composition and feed efficiency in mouse. Genet. Pol. 20:595.

Krider, J. L., B. W. Carroll and E. Roberts. 1946. Effectiveness of selecting for rapid and for slow growth in Hampshire swine. J. Anim. Sci. 5:3.

Kuhlers, D. L. and S. B. Jungst. 1986. Correlated responses in carcass traits to three generations of selection for growth in Landrace pigs. J. Anim. Sci. 63(Suppl. 1) :210 (Abstr.).

Kuhlers, D. L. and S. B. Jungst. 1987. Four generations of mass selection for growth to 200 days of age in Duroc pigs. I. Growth traits. J. Anim. Sci. 65(Suppl. 1):209 (Abstr.).

Laben, R. C. and J. A. Whatley, Jr. 1947. Selection in an inbred line of Duroc swine. J. Anim. Sci. 6:478 (Abstr.).

Lang, B. J. and J. E. Legates. 1969. Rate, composition and efficiency of growth in mice selected for large and small body weight. Theor. Appl. Genet. 39:306.

Leymaster, K. A., L. A. Swiger and W. R. Harvey. 1979. Selection for increased leanness in Yorkshire swine. II. Population parameters, inbreeding effects and response to selection. J. Anim. Sci. 48:800.

Lucas, I. A. M. and A. F. Calder. 1956. The response of different types of pigs to varying levels of feeding from weaning to bacon weight, with particular reference to carcass quality. J. Agric. Sci. 47:287.

Lundstrom, K., E. Dehlberg, L. Nyberg, M. Snochowski, N. Standal and L. E. Edquist. 1983. Glucocorticoid and androgen characteristics in two lines of pigs selected for rate of gain and thickness of backfat. J. Anim. Sci. 56:401.

Malik, R. C. 1984. Genetic and physiological aspects of growth, body composition, and feed efficiency in mice: A review. J. Anim. Sci. 58:577.

Malynicz, G. L. 1974. The effect of feed restriction on growth performance in pigs. Papua New Guinea Agr. J. 25:18 (Nutr. Abstr. and Rev. B: Livestock Feeds and Feeding. 47. No. 427.) (Abstr.).

Maxwell, C. V., D. S. Buchanan, R. O. Bates, F. N. Owens, W. G. Luce and R. Vencl. 1985a. Amino acid supplementation of wheat diets for growing-finishing swine. Okla. Agr. Exp. Sta. MP-117:391.

Maxwell, C. V., D. S. Buchanan, W. G. Luce, R. O. Bates and R. Vencl. 1985b. The effect of wheat versus corn on performance in two lines of growing-finishing swine. Okla. Agr. Exp. Sta. MP-117:387.

McCarthy, J. 1980. Morphological and physiological effects of selection for growth rate in mice. In: A. Robertson (Ed.) Selection experiments in laboratory and domestic animals, July 21-22, 1979. Commonwealth Agricultural Bureaux, pp. 100-109.

McCarthy, J. C. and H. Bakker. 1979. The effects of selection for different combinations of weights at two ages on the growth curve of mice. Theor. Appl. Genet. 55:57.

McPhee, C. P. 1981. Selection for efficient lean growth in a pig herd. Aust. J. Exp. Agric. Anim. Husb. 32:681.

McPhee, C. P. and A. R. Neill. 1976. Changes in the body composition of mice selected for high and low eight week weight. Theor. Appl. Genet. 47:21.

McPhee, C. P., P. C. Trappett, A. R. Neill and F. Duncalfe. 1980. Change in growth, appetite, food conversion efficiency and body composition in mice selected for high postweaning weight gain on restricted feeding. Theor. Appl. Genet. 57:49.

Metz S. H. M., P. L. Bergstrom, N. P. Lenis, M. DeWijs and R. A. Dekker. 1980. The effects of daily energy intake on growth rate and composition of weight gain in pigs. Livest. Prod. Sci. 7:79.

Norton, S. A., M. T. Zavy, D. S. Buchanan, C. V. Maxwell and J. E. Breazile. 1986a. Growth hormone, insulin and glucose secretory patterns in swine selected for rapid versus slow growth rate. J. Anim. Sci. 63(Suppl. 1): 216 (Abstr.).

Norton, S. A., M. T. Zavy, D. S. Buchanan, C. V. Maxwell and J. E. Breazile. 1986b. Plasma growth hormone, insulin and glucose secretory responses to growth hormone releasing factor hGRF$^{(1-44-NH2)}$, arginine and glucose challenges in two lines of gilts selected for rapid versus slow growth. J. Anim. Sci. 63(Suppl. 1):229 (Abstr.).

Notter, D. R., G. E. Dickerson and J. A. DeShazer. 1976. Selection for rate and efficiency of lean gain in the rat. Genetics 84:125.

Park, Y. I., C. T. Hansen, C. S. Chung and A. B. Chapman. 1966. Influence of feeding regime on the effects of selection for post-weaning gain in the rat. Genetics 54:315.

Pidduck, H. G. and D. S. Falconer. 1978. Growth hormone function in mice selected for large and small size. Genet. Res. 32:195.

Prince, T. J., D. L. Kuhlers and S. B. Jungst. 1986. Effects of dietary energy density on performance and carcass characteristics of pigs selected for increased weight at 200 days of age. J. Anim. Sci. 63(Suppl. 1):227 (Abstr.).

Quijandria, B. Jr. and O. W. Robison. 1971. Body weight and backfat deposition in swine: Curves and correction factors. J. Anim. Sci. 33:911.

Rahnefeld, G. W. 1973. Mass selection for post-weaning growth in swine. III. Correlated response in weaning weight and feed efficiency to recurrent selection for post-weaning average daily gain. Can. J. Anim. Sci. 51:497.

Rahnefeld, G. W. and I. Garnett. 1976. Mass selection for post-weaning growth in swine. IV. Selection response and control of population stability. Can. J. Anim. Sci. 56:783.

Richmond, R. J. and R. T. Berg. 1971a. Fat distribution in swine as influenced by liveweight, breed, sex and ration. Can. J. Anim. Sci. 51:523.

Richmond, R. J. and R. T. Berg. 1971b. Muscle distribution in swine as influenced by liveweight, breed, sex and ration. Can. J. Anim. Sci. 51:41.

Richmond, R. J. and R. T. Berg. 1971c. Tissue development in swine as influenced by liveweight, breed, sex and ration. Can. J. Anim. Sci. 51:31.

Rios, J. G., M. K. Nielsen, G. E. Dickerson and J. A. DeShazer. 1986. Selection for postweaning gain in rats: I. Correlated response in feed utilization and body composition. J. Anim. Sci. 63:34.

Roberts, R. C. 1981. The growth of mice selected for large and small size in relation to food intake and efficiency of conversion. Genet. Res. 38:9.

Roberts, R. C. 1979. Side effects of selection for growth in laboratory animals. Livest. Prod. Sci. 6:93.

Robison O. W. 1976. Growth patterns in swine. J. Anim. Sci. 42:1024.

Sather, A. P. and H. T. Fredeen. 1978. Effect of selection for lean growth rate upon feed utilization of market hogs. Can. J. Anim. Sci. 58:285.

Sharp, G. L., W. G. Hill and A. Robertson. 1984. Effect of selection on growth, body composition and food intake in mice. I. Responses in selected traits. Genet. Res. 43:75.

Shields, R. G., D. C. Mahan and P. L. Graham. 1983. Changes in body composition from birth to 145 kg. J. Anim. Sci. 57:43.

Smith, C. and V. R. Fowler. 1978. The importance of selection criteria and feeding regimes in the selection and improvement of pigs. Livest. Prod. Sci. 5:415.

Stahly, T. S. and R. C. Wahlstrom. 1973. Effects of dietary protein level and feed restriction on performance and carcass characteristics of swine. J. Anim. Sci. 36:1109.

Stainer, M. W. and L. E. Mount. 1972. Growth rate, food intake and body composition before and after weaning in strains of mice selected for mature body weight. Br. J. Nutr. 28:307.

Standal, N., B. Tveit, A. Eggum and P. M. Dahl. 1980. Thyroxine and triiodothyronine degradation in lines of pigs selected for rate of gain and thickness of backfat. Acta Agri. Scand. 30:201.

Standal, N. and O. Vangen. 1980. Physiological effects of selection for growth rate and backfat thickness. In: A. Robertson (Ed.) Selection experiments in laboratory and domestic animals, July 21-22, 1979. Commonwealth Agricultural Bureaux, pp. 125-130.

Standal, N., E. Vold, O. Trygstad and I. Foss. 1973. Lipid mobilization in pigs selected for leanness or fatness. Anim. Prod. 16:37.

Steele, N. C. and L. T. Frobish. 1976. Selected lipogenic enzyme activities of swine adipose tissue as influenced by genetic phenotype, age, feeding frequency and dietary energy source. Growth 40:369.

Stephenson, S. K. and R. C. Malik. 1984. Energy partitioning and growth in mice selected for high and low body weight. Genet. Res. 43:323.

Sundstol, F., N. Standal and O. Vangen. 1979. Energy metabolism in lines of pigs selected for thickness of backfat and rate of gain. Acta Agri. Scand. 29:337.

Sutherland, T. M., P. E. Biondini, L. C. Haverland, D. Pettus and W. B. Owen. 1970. Selection for rate of gain, appetite and efficiency of feed utilization in mice. J. Anim. Sci. 31:1049.

Sutherland, T. M., P. E. Biondini and G. M. Wood. 1974. Selected for growth rate, feed efficiency and body composition in mice. Genetics 78:525.

Taylor, J. M. and L. N. Hazel. 1955. The growth curve of pigs between 134 and 174 days of age. J. Anim. Sci. 14:1133.

Tess, M. W., G. E. Dickerson, J. A. Nienaber and C. L. Ferrell. 1986. Growth, development and body composition in three genetic stocks of swine. J. Anim. Sci. 62:968.

Timon, V. M. and E. J. Eisen. 1970. Comparison of ad libitum and restricted feeding of mice selected and unselected for postweaning gain. I. Growth, feed consumption and feed efficiency. Genetics 64:41.

Timon, V. M. and E. J. Eisen. 1969. Comparison of growth curves of mice selected and unselected for postweaning gain. Theor. Appl. Genet. 39:345.

Timon, V. M., E. J. Eisen and J. M. Leatherwood. 1970. Comparison of ad libitum and restricted feeding of mice selected and unselected for postweaning gain. II. Carcass composition and energetic efficiency. Genetics 65:145.

Vangen, O. 1974. Growth rate and feed conversion of lines of pigs selected for rate of gain and thickness of backfat. Acta Agri. Scand. 24:309.

Vangen, O. 1980a. Studies on a two trait selection experiment in pigs. III. Correlated responses in daily feed intake, feed efficiency and carcass traits. Acta Agri. Scand. 30:125.

Vangen, O. 1980b. Studies on a two trait selection experiment in pigs. IV. Estimated maintenance requirements from feeding experiments. Acta Agri. Scand. 30:142.

Vangen, O. 1979. Studies on a two trait selection experiment in pigs. II. Genetic changes and realized genetic parameters in the traits under selection. Acta Agri. Scand. 29:305.

Vangen, O. 1977. Studies on a two trait selection experiment in pigs. I. Growth, feed consumption and feed conversion ratio after 10 years of selection for growth rate and backfat thickness. Acta Agri. Scand. 27:331.

Vanschoubroeck, F., R. DeWilde and P. Lampo. 1967. The quantitative effects of feed restriction in fattening pigs on weight gain, efficiency of utilization and backfat thickness. Anim. Prod. 9:67.

Wang, C. T., G. E. Dickerson, S. E. Hadden and R. D. Allrich. 1980. Physiological responses to selection for rate of efficiency of postweaning gain in rats. In: A. Robertson (Ed.) Selection experiments in laboratory and domestic animals, July 21-22, 1979. Commonwealth Agricultural Bureaux, pp. 112-113.

Wangsness, P. J., R. J. Martin and J. H. Gagagan. 1977. Insulin and growth hormone in lean and obese pigs. Am. J. Physiol. 233:E104.

Wangsness, P. J., R. J. Martin and B. B. Gatchel. 1980. Insulin induced growth hormone response in fast-growing, lean and in slow-growing, obese pigs. Growth 44:318.

Webb, A. J. and J. W. B. King. 1983. Selection for improved food conversion on ad libitum group feeding in pigs. Anim. Prod. 37:375.

Whittemore, C. T. 1979. Nutritional advice to geneticists. European Pig Testing Conference. Harrogate, England.

Woltmann, M. D., D. S. Buchanan and R. Vencl. 1987. Front leg soundness scores of swine selected for rapid versus slow growth rate. Okla. Agr. Exp. Sta. MP-119:19.

Wood, J. P., O. P. Wholeham, M. Ellis, W. C. Smith and R. Laird. 1983. Effects of selection for low backfat thickness in pigs on the sites of tissue deposition in the body. Anim. Prod. 36:389.

Yuksel, E. 1979. Genetic aspects of the efficiency of food utilization in some farm and laboratory animals. Anim. Breed. Abstr. 47:499.

Yuksel, E., W. G. Hill and R. C. Roberts. 1981. Selection for efficiency of feed utilization in growing mice. Theor. Appl. Genet. 59:129.

CHAPTER III

# GROWTH AND CARCASS OF PIGS SELECTED FOR RAPID OR SLOW POSTWEANING GROWTH AND FED AD LIBITUM OR LIMITED RATIONS

## Summary

Lines of pigs selected for rapid (RGL) or slow (SGL) postweaning growth were evaluated at ad libitum (AL) or restricted (LIM) (83% of predicted ad libitum) feed intake levels. Barrows were fed over a constant time interval either individually or as littermate pairs from 35 kg (ONWT) through an average weight of 105 kg (OFWT). Initial carcass composition was determined from slaughter data of one representative barrow from each litter. Carcass data at ONWT indicated few line differences. In a spring-farrowing replicate, a total of 90 ONWT and 180 OFWT barrows from generations 2, 3 and 4 of divergent selection were evaluated. In a fall-farrowing replicate, 18 ONWT and 36 OFWT barrows were evaluated from the third generation of selection. In the spring replicate, barrows from the RGL-AL gained 20.8% faster, consumed 17.5% more feed and had 15.8% more backfat than SGL-AL barrows. When intake differences were removed the RGL was 6.7% more efficient and gained 8.1% faster, with no differences in backfat. Daily gain tended to increase in the RGL-AL and decrease in the SGL-AL with generation of selection, while gain under limited intake did not change with generation in either line. In the fall replicate, RGL-AL pigs gained

9.1% faster, consumed 17.6% more feed and had 17.1% more backfat than SGL-AL pigs, with no line differences when intake was limited to the same level. Ad libitum intake was higher in the fall farrowing replicate, thus restriction to the same intake as in the spring resulted in a more severe percent restriction. At the end of the test period, carcass data were collected, including physical separation of lean, fat and bone. In both replicates, SGL-AL pigs had a higher percent lean and a lower percent fat than RGL-AL, with no differences when the two lines received LIM. In the spring, lean growth was 12.1% higher in RGL-AL than SGL-AL, while there were no differences in efficiency of lean growth. Comparing the two lines on LIM, the RGL gained lean 9.1% faster and deposited lean 8% more efficiently. These findings suggest the major correlated change associated with selection for growth is intake and much of the increase in intake is utilized for the deposition of fat.

(Key Words: Correlated Responses, Growth, Intake, Pigs, Selection)

## Introduction

Successful selection for growth or body weight (BW) in swine has been reported by a number of studies. Hampshire pigs selected for high or low 150-day weight diverged by 28.1 kg at 180 d after nine generations of selection (Baird et al., 1952). High-line Hampshires consumed more feed and were more efficient. Selection for increased weight at a given age (Fine and Winters, 1953; Kuhlers and Jungst, 1986; Jungst and Kuhlers, 1987; Kuhlers and Jungst, 1987), decreased size (Dettmers et al., 1965) and increased postweaning gain (Rahnefeld, 1973;

Rahnefeld and Garnett, 1976; Sather and Fredeen, 1978) has also been successful.

Mice selected for large body size (Stainer and Mount, 1972) or fast growth (Timon and Eisen, 1970) gained more and were more efficient than non-selected controls when restricted to the same level of intake. This suggests efficiency is the major correlated trait associated with selection for increased growth. In opposition of this, Roberts (1981) found large mice were slower growing than controls when restricted to the controls level of intake. This would suggest intake is the major correlated trait associated with selection for increased growth. Presently, there are no reported studies in which lines of pigs undergoing single-trait selection for divergent growth were compared at the same level of intake. Cleveland et al. (1983) restricted an index line selected for increased growth and decreased backfat to either 91 or 82% of ad libitum feed intake. Select and control lines differed by 9% when fed ad libitum and 5% when restricted to 82%. Protein gain was decreased by 20 and 13% in the select and control lines, respectively, when fed at the 82% level of intake.

The goal of the swine industry should be production of lean tissue as quickly and efficiently as possible. Two traits associated with postweaning growth are lean tissue growth rate (LTGR) defined as lean gain per day and lean tissue feed conversion (LTFC) which is lean gain per feed consumed (Fowler et al, 1976). The objectives of this study were to 1) evaluate differences in LTGR and LTFC in lines selected for divergent postweaning growth; 2) compare differences in LTGR and LTFC when variation in intake was eliminated and 3) investigate the relationship between LTGR and LTFC and other growth and performance traits in barrows selected for divergent growth when fed either ad libitum or restricted diets.

## Materials and Methods

### Initiation of lines

Lines of pigs were established in 1980 and 1981 at the Southwest Livestock and Forage Research Station located near El Reno, Oklahoma. Litters sired by either high- or low-indexing Hampshire boars farrowed during the spring and fall of 1980. The females used were three- and four-breed cross gilts consisting of Duroc, Spotted, Yorkshire and Landrace breeding. A description of the development of these crossbred females is given by Buchanan and Johnson (1984) and McLaren et al. (1987ab). In 1981, offspring from the initial matings were randomly bred to either high- or low-indexing Duroc boars. Hampshire and Duroc boars were purchased in breed pairs from central test stations located in Iowa, Missouri, Nebraska and Oklahoma. One boar of each pair had an index of at least 118, while the other had an index value of less than 90. Boars were evaluated on the index that was recommended by the National Swine Improvement Federation, $I + 100 + 60 (G - \bar{G}) - 75 (F - \bar{F}) - 70 (B - \bar{B})$ (Hubbard, 1981). Individual average daily gain, adjusted backfat and pen feed efficiency are represented by G, B and F respectively, while test means for each trait are represented by $\bar{G}$, $\bar{B}$ and $\bar{F}$. A comparison of the high- and low-indexing boars and their progeny has previously been provided by Bates and Buchanan (1988). Litters born in 1981 were used to initiate rapid (RGL) and slow (SGL) growth lines. Both lines were closed to outside genetics starting with the 1981-born pigs.

To establish the RGL, selection for rapid postweaning ADG from 9 wk of age through 100 kg was practiced on boars sired by high-indexing Duroc boars and out of females sired by high indexing-Hampshire boars (HH). They were mated to gilts of similar genetic make-up (HH), as well as females sired by high-indexing Duroc boars and out of females sired by low-indexing Hampshire boars (HL). Mass selection for postweaning average daily gain was practiced across the HH and HL groups of gilts combined. The HL gilts were included because of insufficient numbers of HH females to establish the line.

The SGL was established in much the same way. Selection for slow postweaning gain was practiced on boars sired by low-indexing Duroc boars and out of females sired by low indexing Hampshire boars (LL). Females of the same genetic make-up (LL), as well as gilts sired by low-indexing Duroc boars and out of females sired by high-indexing Hampshire boars (LH) were mass selected for slow postweaning gain.

General design and management of the lines

After the lines were established, divergent selection growth was continued in the RGL and SGL. One-hundred percent replacement of boars and gilts resulted in a generation interval of 1 yr. Each line was maintained with 50 females and eight males. In the initial 2 yr of the project, approximately 48 boars were tested per season. For the remainder of the project this number was reduced to about 36 in order to accommodate the need for barrows for the current project (described in the section on experimental design). Boars were randomly selected within each litter and tested in littermate pairs whenever possible.

Mass selection was practiced among all gilts. The selection criterion in both sexes was ADG from 9 wk of age through 100 kg.

All pigs, including boars, were housed in two adjacent confinement barns. The barns consist of solid concrete flooring with modified sides which could be opened during warm weather. Pigs were moved to one of the barns at 8 wk of age and given a 1 wk adjustment period prior to starting test. They were grouped in pens of approximately 16 to 18 pigs, with littermates remaining within the same pen whenever possible. Weights were recorded when the pen averaged approximately 54 kg to separate the growing and finishing phases. Nutritional trials were imposed on both lines for the growing and finishing phases. Care was taken to cross-classify nutritional treatments with line. Boars were penned separately and assigned to a control ration. Each pen was weighed weekly once a pig within the pen was estimated to have reached 100 kg. Pigs were removed from test the first week they reached 100 kg. Upon removal from test, pigs were measured for backfat with an ultrasonic probe at the shoulder, the last rib and the last lumbar vertebrae. Total feed consumption for each pen was recorded for both the growing and finishing phases.

Once removed from test, individuals retained as replacements were moved from the confinement barns into dirt lots. Gilts were hand-mated at approximately 8 mo of age and remained on dirt until entering the farrowing house. Nutrition trials were also imposed on the gestating females. Sows and litters were moved to a nursery about one week after farrowing, where they remained until weaning at 42 d post-farrowing. The litter remained in the pen for an additional 2 wk after weaning. At 3 wk of age creep feed was made available to the piglets and boars were castrated. Weights were recorded on the bred gilts at breeding, 109 d of gestation and weaning. Pigs were weighed at birth, 21 d and 42 d.

Two replicates of the selection lines were maintained. The spring replicate farrowed during mid-March through April, while the fall replicate farrowed from mid-September through October.

Experimental design

A total of 216 market weight barrows and 108 thirty-five kg barrows from four farrowing seasons were used to evaluate the RGL and SGL at two levels of feed intake. Starting with pigs farrowed in the spring of 1983, which represented two generations of divergent selection for gain, three barrows per litter were randomly selected from 36 litters for testing. One of the barrows from each litter was slaughtered at approximately 35 kg to determine compositional differences between lines at on-test wt. The remaining two barrows were fed together in a pen approximately six square meters in size. The pairs of barrows were arranged in a 2 x 2 factorial in which pens representing each of the lines were assigned either an ad libitum ration (AL) or a ration limited to 83% of predicted ad libitum intake (LIM). There were 36 pens available, so nine blocks of the 2 x 2 factorial arrangement were tested, for a total of 72 pigs. All limit-fed pigs within a block received the same amount of feed daily. This level of intake was based on 83% of predicted ad libitum for the average weight all LIM pigs within that block. Ad libitum intake was predicted from an equation based on previous barrow intake data from the RGL and SGL and calculated using metabolic weight (empty body weight$^{.75}$). Intake levels of the LIM pigs were adjusted weekly. All pigs within a block were removed from test when the block averaged approximately 105 kg.

Barrows on both levels of intake were fed the same diet (Table 1), which was corn-soybean meal based and calculated to meet the nutrient needs of the growing pig on ad libitum intake (NRC, 1979). Due to constraints on the number of pigs that could be slaughtered in a given week many blocks were removed at heavier weights, with some blocks reaching average weights as high as 120 kg. After removal from test the pigs were taken to Stillwater and slaughtered at the Oklahoma State University Meat Laboratory facilities.

Due to financial constraints, barrows from the fall of 1983 season were sold. The same design was used for the pigs farrowed in the spring of 1984, but carcass data were not collected on two of the blocks due to illness of one or more of the pigs within the block. All other data were collected for these two blocks. For the following two seasons (fall of 1984 and spring of 1985), the number of litters included was reduced by one-half. One barrow from each litter was slaughtered at 35 kg, while one was assigned to AL and the other to LIM. Carcass data were collected on all market weight barrows from both of these seasons. For a summary of the number of barrows used in this study refer to table 2.

Data collected on the growing-finishing pigs included weekly weight and feed intake starting at on-test and weekly backfat probes starting at approximately 70 kg. Backfat probes were taken ultrasonically at the shoulder, the last rib and the last lumbar vertebrae. Carcass data collected included slaughter wt, carcass length, backfat measurements,

TABLE I

COMPOSITION OF THE DIET[a]

| Ingredient | Percent |
|---|---|
| Ground corn | 76.87 |
| Soybean meal | 19.53 |
| Dicalcium phosphate | 1.64 |
| Calcium carbonate | 0.82 |
| Salt | 0.40 |
| Vitamin-trace mineral | 0.25 |
| Tylan 10 | 0.50 |

[a]Balanced to 0.75% lysine and contains approximately 16 % crude protein.

TABLE II

NUMBER OF PIGS

| Replicate | Generation | Initial[a] | Tested |
|---|---|---|---|
| Spring 1983 | 2 | 36 | 72 |
| Spring 1984 | 3 | 36 | 72[b] |
| Fall 1984 | 3 | 18 | 36 |
| Spring 1985 | 4 | 18 | 36 |

[a]Slaughtered at on-test weight.
[b]Carcass data were not collected on 16 pigs (2 replicates).

right side carcass wt and loin eye area. The right side of each carcass was divided into the four major wholesale cuts of the ham, loin, shoulder and belly (Carr, 1975). Each of these cuts was then physically separated into fat, bone and very closely trimmed lean. The lean was combined, ground and three 110 g samples were taken for ether extract analysis in order to estimate fat-free lean. In addition, the biceps femoris and the semitendinosus were removed from the ham for ether extract analysis.

Lean composition of the tested barrows at on-test weight was estimated from carcass data on littermate barrows slaughtered at 35 kg. Estimates were based on a prediction equation found by regressing total dissected lean on slaughter weight. Lean gain in the tested barrows was estimated by the difference between total dissected carcass lean and predicted lean at on-test weight. This allowed the estimation of lean tissue feed conversion (LTFC) and lean tissue growth rate (LTGR), as described by Fowler et al. (1976).

The biceps femoris, semitendinosus and the combined lean samples were homogenized using a Sorvall Omni-Mixer. Two 3.0 g subsamples were taken from each of the three homogenized samples and moisture was determined (AOAC, 1980) using a Thelco drying oven. Dried samples were used to determine the percent ether extract by use of the soxlet method (AOAC, 1980). The duplicate samples were averaged to predict percent ether extract and an individual sample was analyzed again if the difference between duplicate samples was greater than 10%.

Statistical Analysis

The data were analyzed as a blocked factorial using the General Linear Models procedure in SAS (1985). Pen was considered the experimental unit, so in those replicates in which littermate pairs were fed together pen averages were analyzed. The spring and fall replicates were analyzed as separate data sets. The effects of line, level of feed intake, generation of selection, all possible two-way interactions, the three-way interaction and block within generation were included in the analysis of all growth and performance traits in the spring replicate. A similar model was used in the fall replicate, with the effects of line, level of feed intake, the line x level of feed intake interaction and block included. All non-significant interactions and block effects ($P>.20$), with the exception of line x level of intake, were removed from the final models of both replicates. The model used to analyze carcass data from the pigs slaughtered at on-test weight in the spring replicate included line, generation and the interaction, while line was the only effect in the analysis of the fall data. The line x generation interaction was removed from the final model used for the spring replicate when found to be non-significant ($P>.20$).

Growth, intake and backfat curves were fit using a method that removed the correlation due to repeated measurements on an animal (Allen et al., 1983). Quadratic regressions were fit by pen in both replicates and the resulting coefficients (intercept, linear and quadratic) were analyzed using the models described previously for the growth and carcass traits. Again, all non-significant effect interactions and block effects were removed from the final model. Functions for subclass curves were determined from appropriate least squares means estimates (SAS, 1985).

## Results and Discussion

Slaughter data from pigs at on-test weight indicates few line differences in either the spring or fall replicate. Slaughter wt tended ($P<.10$) to be heavier for the RGL in the spring replicate (Table III). In addition, RGL pigs were about 1 wk younger at on-test (Table VII). Carcass backfat was significantly lower ($P<.05$) in SGL pigs from the spring replicate (Table III); however, there was no line difference in either the amount of total dissected fat or fat as a percent of total carcass wt (Table IV). In the fall replicate the RGL tended ($P<.10$) to have a higher percent fat and lower percent fat-free lean. This may in part be due to the heavier on-test wt of the fall replicate. Dissected fat from the loin, both as a percent of carcass wt (Table V) and total carcass wt (Table VI), was significantly higher in the RGL ($P<.01$). This indicates selection for divergent growth may cause fat redistribution as early as 40 kg.

Separate equations were developed for each replicate to predict initial lean content. For both replicates the interactions of line and generation within the spring replicate with the linear and quadratic effects of on-test wt were found to be non-significant, and thus removed from the final models. The following equations were used to predict initial lean wt in the spring replicate:

$$\text{Total lean} = -3.17 + (.221 \times \text{on-test wt})$$

and the fall replicate:

TABLE III

LEAST-SQUARES MEANS FOR CARCASS MEASUREMENTS AT ON-TEST WEIGHT

| Replicate | Spring | | | Fall | | |
|---|---|---|---|---|---|---|
| Line[a] | RGL | SGL | SE | RGL | SGL | SE |
| Slaughter wt, kg | 40.5 | 38.0+ | 0.97 | 50.8 | 48.1 | 1.89 |
| Loin eye area, $cm^2$ | 12.6 | 11.6 | 0.01 | 17.2 | 17.5 | 0.02 |
| Carcass length[b] | 59.7 | 56.9+ | 0.19 | 64.5 | 63.5 | 0.14 |
| Average backfat[b] | 1.50 | 1.40* | 0.01 | 1.68 | 1.55 | 0.01 |
| Backfat shoulder[b] | 2.34 | 2.21+ | 0.01 | 2.51 | 2.36 | 0.02 |
| Backfat last rib[b] | 1.09 | 0.97* | 0.01 | 1.19 | 1.17 | 0.02 |
| Backfat last lumbar[b] | 1.09 | 1.02+ | 0.01 | 1.30 | 1.17 | 0.02 |

*Line means for the spring replicate differ ($P < .05$).
+Line means for the spring replicate differ ($P < .10$).
[a]RGL = rapid growth line, SGL = slow growth line.
[b]Carcass backfat in cm.

## TABLE IV

## LEAST-SQUARES MEANS FOR CARCASS COMPOSITION AT ON-TEST WEIGHT

| Replicate | Spring | | | Fall | | |
|---|---|---|---|---|---|---|
| Line[a] | RGL | SGL | SE | RGL | SGL | SE |
| Percent lean[b] | 65.0 | 65.2 | 0.39 | 62.2 | 64.2 | 0.98 |
| Percent fat[b] | 19.3 | 18.8 | 0.34 | 23.5 | 20.7+ | 1.12 |
| Percent bone[b] | 15.7 | 15.9 | 0.27 | 14.3 | 15.1 | 0.39 |
| Total lean[c] | 7.3 | 7.0 | 0.23 | 9.8 | 9.4 | 0.31 |
| Total fat[c] | 2.2 | 2.0 | 0.08 | 3.7 | 3.1 | 0.28 |
| Total bone[c] | 1.7 | 1.7 | 0.04 | 2.2 | 2.2 | 0.07 |
| Ether extract, % | 13.0 | 12.9 | 0.92 | 18.2 | 14.0 | 2.47 |
| Fat-free lean[d], % | 56.6 | 56.8 | 0.72 | 50.8 | 55.2+ | 1.61 |
| Moisture, % | 70.7 | 69.7 | 1.68 | 66.3 | 63.5 | 2.53 |

+Line means for the fall replicate differ ($P < .10$).
[a]RGL = rapid growth line, SGL =slow growth line.
[b]Expressed as a percentage of chilled carcass weight.
[c]Right side of the chilled carcass (kg).
[d]Total lean - (total lean x ether extract).

TABLE V

LEAST-SQUARES MEANS FOR THE PERCENT COMPOSITION OF THE MAJOR WHOLESALE CUTS AT ON-TEST WEIGHT[a]

| Replicate Line[b] | Spring RGL | Spring SGL | Spring SE | Fall RGL | Fall SGL | Fall SE |
|---|---|---|---|---|---|---|
| Lean ham | 18.7 | 18.7 | .17 | 17.2 | 18.7* | .38 |
| Fat ham | 5.2 | 5.2 | .12 | 5.3 | 5.2 | .28 |
| Bone ham | 4.0 | 4.0 | .09 | 3.2 | 3.7* | .16 |
| Lean loin | 15.6 | 15.6 | .16 | 15.3 | 15.8 | .31 |
| Fat loin | 5.6 | 5.0** | .15 | 7.1 | 6.1 | .55 |
| Bone loin | 4.4 | 4.5 | .10 | 4.3 | 4.5 | .17 |
| Lean shoulder | 19.5 | 19.7 | .19 | 18.4 | 19.2 | .46 |
| Fat shoulder | 4.6 | 5.0 | .16 | 6.2 | 5.1* | .35 |
| Bone shoulder | 5.1 | 5.3 | .13 | 4.6 | 5.1 | .20 |
| Lean belly | 11.2 | 11.2 | .19 | 11.3 | 10.5 | .64 |
| Fat belly | 3.8 | 3.8 | .16 | 5.0 | 4.2 | .50 |
| Bone belly | 2.2 | 2.2 | .08 | 2.1 | 1.8+ | .14 |

**Line means differ ($P < .01$).
*Line means differ ($P < .05$).
+Line means differ ($P < .10$).
[a]Expressed as a percentage of right-side chilled carcass weight.
[b]RGL= rapid growth line, SGL = slow growth line.

TABLE VI

LEAST-SQUARES MEANS FOR WEIGHTS OF THE MAJOR WHOLESALE CUTS AT ON-TEST WEIGHT[a]

| Replicate | Spring | | | Fall | | |
|---|---|---|---|---|---|---|
| Line[b] | RGL | SGL | SE | RGL | SGL | SE |
| Lean ham | 2.10 | 2.01 | .06 | 2.71 | 2.73 | .08 |
| Fat ham | 0.59 | 0.56 | .02 | 0.84 | 0.77 | .06 |
| Bone ham | 0.45 | 0.43 | .01 | 0.50 | 0.54 | .02 |
| Lean loin | 1.75 | 1.68 | .05 | 2.41 | 2.32 | .10 |
| Fat loin | 0.64 | 0.54** | .03 | 1.14 | 0.92 | .12 |
| Bone loin | 0.49 | 0.47 | .01 | 0.68 | 0.67 | .03 |
| Lean shoulder | 2.20 | 2.12 | .07 | 2.90 | 2.81 | .12 |
| Fat shoulder | 0.53 | 0.53 | .02 | 0.98 | 0.74* | .07 |
| Bone shoulder | 0.57 | 0.56 | .02 | 0.73 | 0.74 | .03 |
| Lean belly | 1.28 | 1.22 | .05 | 1.78 | 1.52+ | .10 |
| Fat belly | 0.42 | 0.40 | .02 | 0.78 | 0.64 | .09 |
| Bone belly | 0.24 | 0.23 | .01 | 0.34 | 0.26* | .02 |

**Line means differ (P < .01).
*Line means differ (P < .05).
+Line means differ (P < .10).
[a]Right-side chilled carcass weight (kg).
[b]RGL = rapid growth line, SGL = slow growth line.

TABLE VII

LEAST-SQUARES MEANS FOR PERFORMANCE TRAITS IN THE SPRING REPLICATE

| Line[a] | RGL | | SGL | | |
|---|---|---|---|---|---|
| Level of intake[a] | AL | LIM | AL | LIM | SE |
| On-test wt, kg | 38.5 | 39.6 | 38.5 | 38.2 | 0.55 |
| On-test age, d[b] | 88.1 | 87.9 | 95.8 | 94.2 | 0.84 |
| Off-test wt, kg | 116.2 | 107.3 | 102.8 | 100.7 ** | 1.02 |
| ADG, kg/d[c] | 0.93 | 0.80 | 0.77 | 0.74** | 0.01 |
| Feed/gain | 3.42 | 3.19 | 3.52 | 3.42* | 0.03 |
| Daily intake, kg[c] | 3.15 | 2.55 | 2.68 | 2.53** | 0.03 |
| Average backfat[d] | 3.30 | 2.86 | 2.94 | 2.81** | 0.05 |
| Backfat shoulder[d] | 4.97 | 4.35 | 4.42 | 4.29** | 0.08 |
| Backfat last rib[d] | 2.42 | 2.11 | 2.13 | 2.03* | 0.05 |
| Backfat last lumbar[d] | 2.52 | 2.10 | 2.26 | 2.10* | 0.05 |

**Significant line x level of intake interaction (P < .01).
*Significant line x level of intake interaction (P < .05).
[a]RGL = rapid growth line, SGL = slow growth line, AL = ad libitum, LIM = limited to 83 % of predicted ad libitum.
[b]Line means differ (P < .01).
[c]Line x level of intake x generation interaction significant (see tables VIII and IX).
[d]Probed backfat in cm.

Total lean = 5.49 + (.144 x on-test wt).

The interaction of line x level of intake x generation was significant ($P<.05$) for ADG and daily intake (Tables VIII and IX), in the spring replicate. Similar patterns were seen for both traits when pigs were fed AL. The RGL tended to increase and the SGL tended to decrease with generation of selection. When restricted, both lines had similar intake levels; however, RGL pigs gained faster than SGL pigs in the third and forth generations. In the latter two generations SGL pigs had similar daily intakes under ad libitum and restricted levels, indicating that SGL pigs fed 83 % of predicted ad libitum were not restricted. The RGL was more efficient under both levels of intake, with a larger difference when intake was restricted (7.2 vs 2.9%) (Table VII), resulting in an interaction of line x level of intake ($P<.05$).

In the fall replicate, RGL-AL pigs gained 9.1% faster than SGL-AL barrows (Table X), while gain did not differ in the two lines fed LIM. The effects of limit feeding on ADG were more severe than seen in the spring replicate. Gain was reduced by 27 and 18% for the RGL and SGL, respectively. This appears to be due largely to a more severe feed restriction in the fall replicate. Intake levels were essentially the same across replicates for LIM pigs. However, fall replicate AL barrows had much higher intakes (12.2% in the RGL and 14.5% in the SGL), as compared to AL barrows from the spring replicate. Pigs from the spring replicate are tested during the summer months (June through September), while fall-replicate pigs are tested during the winter months (December through March). This indicates seasonal temperature differences may

TABLE VIII

LEAST-SQUARES MEANS FOR THE LINE X LEVEL OF INTAKE X GENERATION INTERACTION FOR AVERAGE DAILY INTAKE (KG) IN THE SPRING REPLICATE[ab]

| Line[c] | RGL | | SGL | |
|---|---|---|---|---|
| Level of intake[c] | AL | LIM | AL | LIM |
| Generation 2 | 3.06 | 2.52 | 2.87 | 2.52 |
| Generation 3 | 3.30 | 2.58 | 2.61 | 2.57 |
| Generation 4 | 3.08 | 2.55 | 2.56 | 2.49 |

[a]Interaction significant (P < .05).
[b]SE = 0.06.
[c]RGL =rapid growth line, SGL = slow growth line, AL = ad libitum, LIM = limited to 83 % of predicted ad libitum.

TABLE IX

LEAST-SQUARES MEANS FOR THE LINE X LEVEL OF INTAKE X GENERATION INTERACTION FOR AVERAGE DAILY GAIN (KG) IN THE SPRING REPLICATE[ab]

| Line[c] | RGL | | SGL | |
|---|---|---|---|---|
| Level of intake[c] | AL | LIM | AL | LIM |
| Generation 2 | 0.89 | 0.79 | 0.83 | 0.75 |
| Generation 3 | 0.98 | 0.82 | 0.73 | 0.75 |
| Generation 4 | 0.91 | 0.80 | 0.72 | 0.72 |

[a]Interaction significant (P < .05).
[b]SE = 0.02.
[c]RGL = rapid growth line, SGL = slow growth line, AL = ad libitum, LIM = limited to 83 % of predicted ad libitum.

TABLE X

LEAST-SQUARES MEANS FOR PERFORMANCE TRAITS IN THE FALL REPLICATE

| Line[a] | RGL | | SGL | | |
|---|---|---|---|---|---|
| Level of intake[a] | AL | LIM | AL | LIM | SE |
| On-test wt, kg | 50.3 | 48.4 | 45.4 | 47.1 | 1.50 |
| On-test age, d | 112.3 | 112.4 | 114.7 | 114.7 | 1.94 |
| Off-test wt, kg | 109.4 | 91.6 | 99.9 | 91.7* | 2.05 |
| ADG, kg/d | 0.99 | 0.72 | 0.90 | 0.74** | 0.02 |
| Feed/gain[b] | 3.64 | 3.56 | 3.40 | 3.40 | 0.07 |
| Daily intake, kg | 3.61 | 2.54 | 3.07 | 2.53** | 0.07 |
| Average backfat[bcd] | 3.33 | 2.66 | 2.98 | 2.46 | 0.08 |
| Backfat shoulder[bcd] | 4.77 | 4.11 | 4.56 | 3.87 | 0.11 |
| Backfat last rib[bcd] | 2.52 | 1.87 | 2.14 | 1.77 | 0.10 |
| Backfat last lumbar[bcd] | 2.69 | 1.99 | 2.24 | 1.76 | 0.08 |

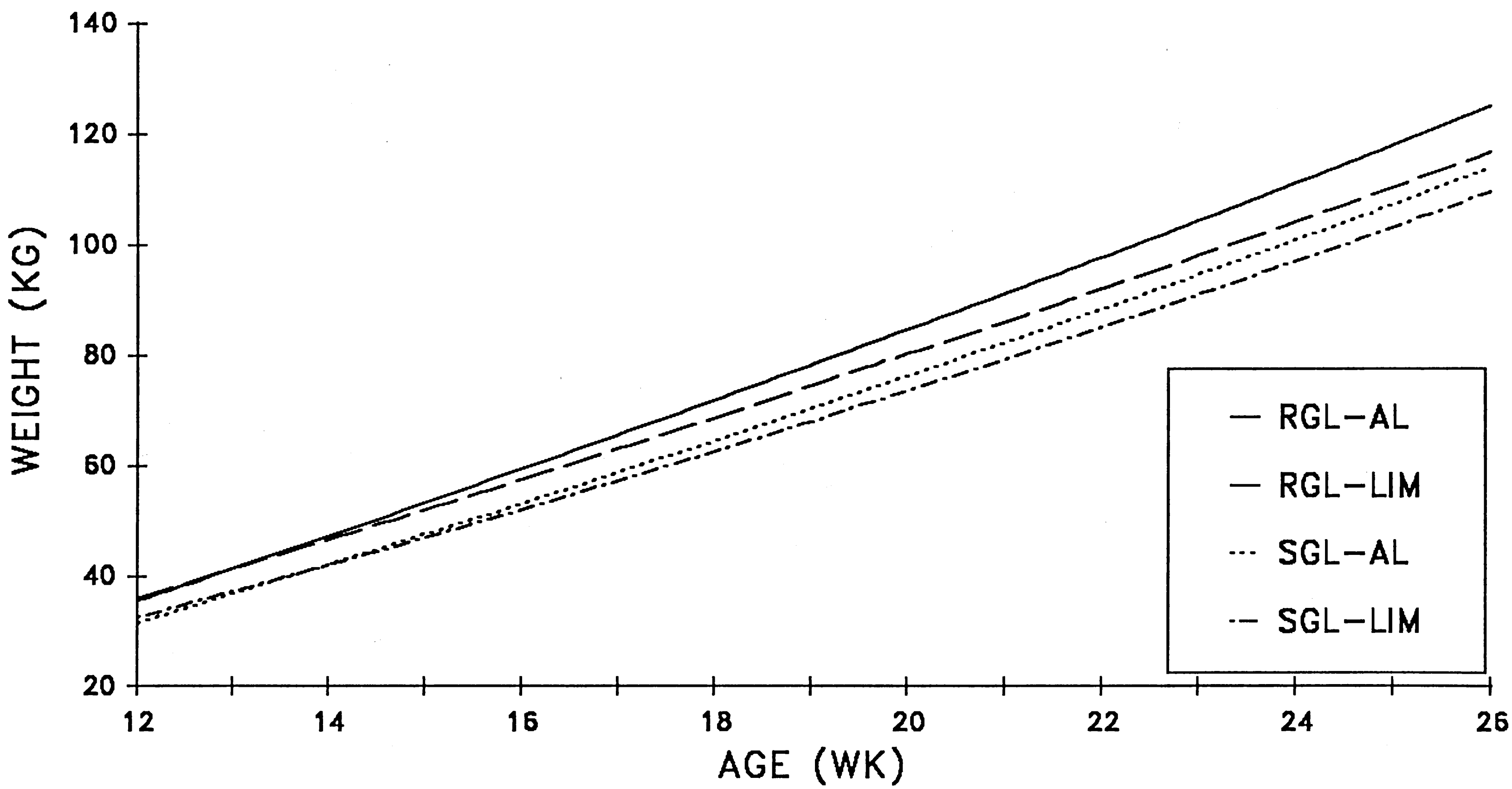
**Significant line x level of intake interaction (P < .01).
*Significant line x level of intake interaction (P < .05).
[a]RGL = rapid growth line, SGL = slow growth line, AL = ad libitum, LIM = limited to 83 % of predicted ad libitum.
[b]Line means differ (P < .05).
[c]Level of intake means differ (P < .05).
[d]Probed backfat in cm.

play a role in affecting changes correlated with selection for increased growth.

In the fall replicate gain, in LIM pigs was similar in both lines while in the spring the RGL-LIM maintained an advantage in gain that increased with generation of selection (Table IX). This suggests most of the improvement in gain in the fall replicate was due to increased intake, while increased ADG in the spring replicate was due to a combination of higher intakes and improved efficiency.

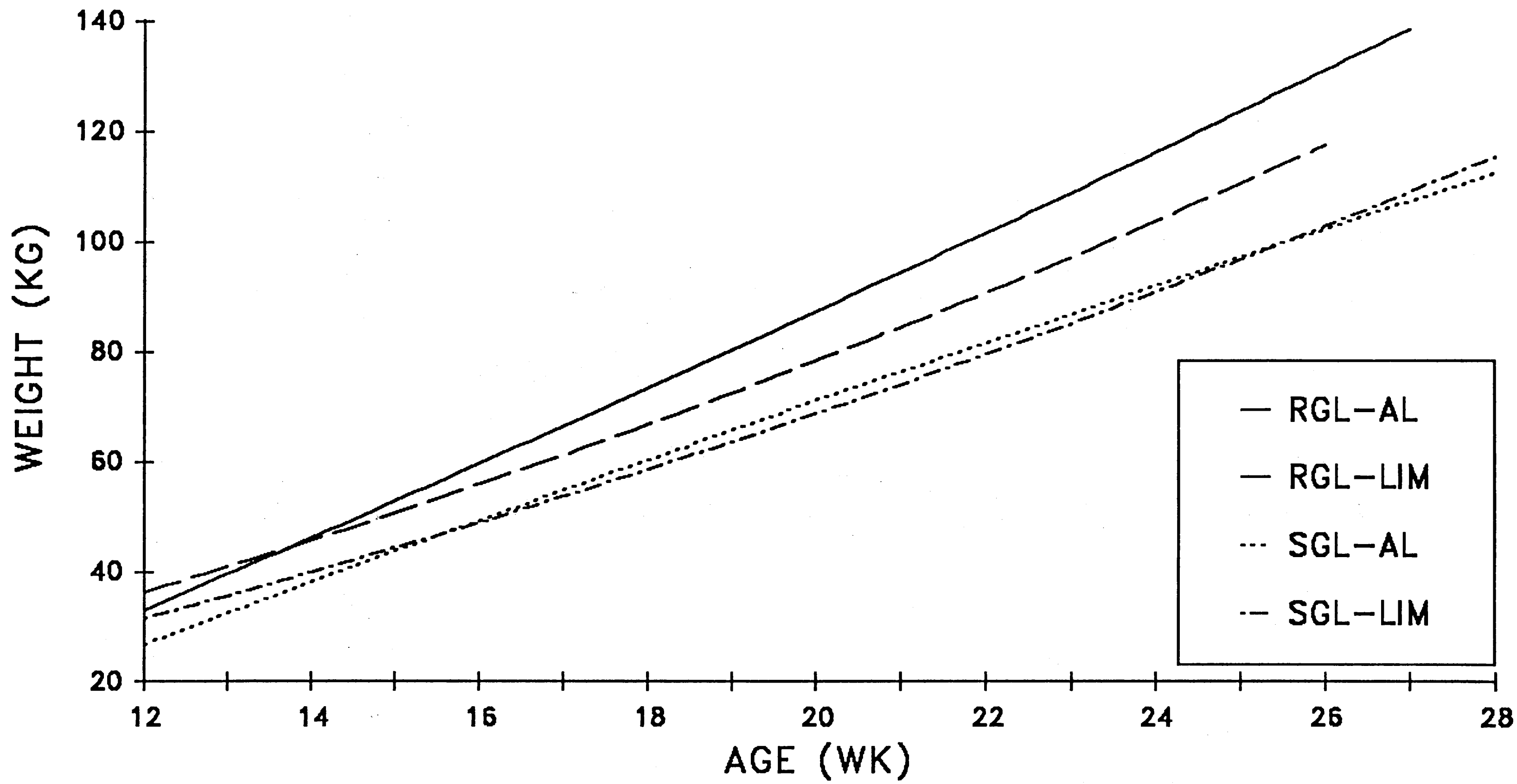
A line of pigs selected for fast postweaning growth was more efficient and had higher intakes than a line selected for slow growth (Baird et al., 1952). Percent changes in efficiency and intake were similar in mice selected for 21 to 42 d growth (Brown and Frahm, 1975), with much the same results reported in rats (Rios et al., 1986). In reviewing selection for growth in mice, Roberts (1979) indicated that selection for increased growth improved F/G and increased feed intake. In a separate review by McCarthy (1980) it was concluded that selection for increased body size or gain improves efficiency, while downward selection results in less efficient mice.

Regression of BW on age in the spring (Figures 1 through 3) and fall (Figure 4) replicates corresponds with the three and two-way interactions for ADG in the two replicates, respectively. The first three figures illustrate the divergence in growth due to selection, with very little difference between the two levels of intake in the SGL. In the fall replicate, ranking of the subclass curves change, with the RGL-LIM falling to the level of the SGL-LIM. In reviewing growth patterns in swine, Robison (1974) found postweaning weight curves were



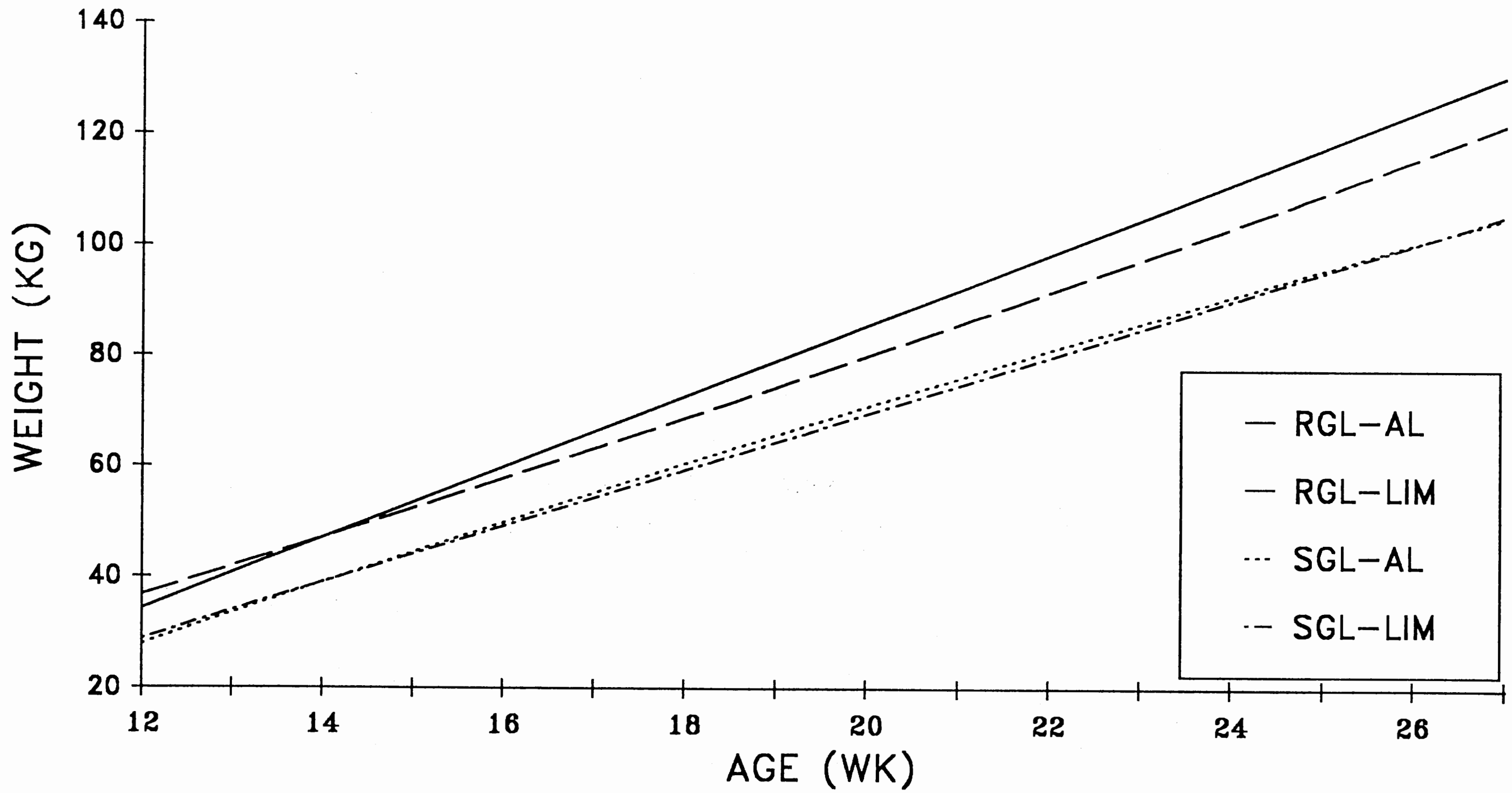

RGL-AL: Weight = $-29.22 + 4.930*wk + 0.0382*wk^2$
RGL-LIM: Weight = $-21.01 + 4.290*wk + 0.0386*wk^2$
SGL-AL: Weight = $-24.54 + 4.113*wk + 0.0464*wk^2$
SGL-LIM: Weight = $-14.65 + 3.200*wk + 0.0606*wk^2$

Figure 1. Regression on Weight on Age in Generation Two of the Spring Replicate



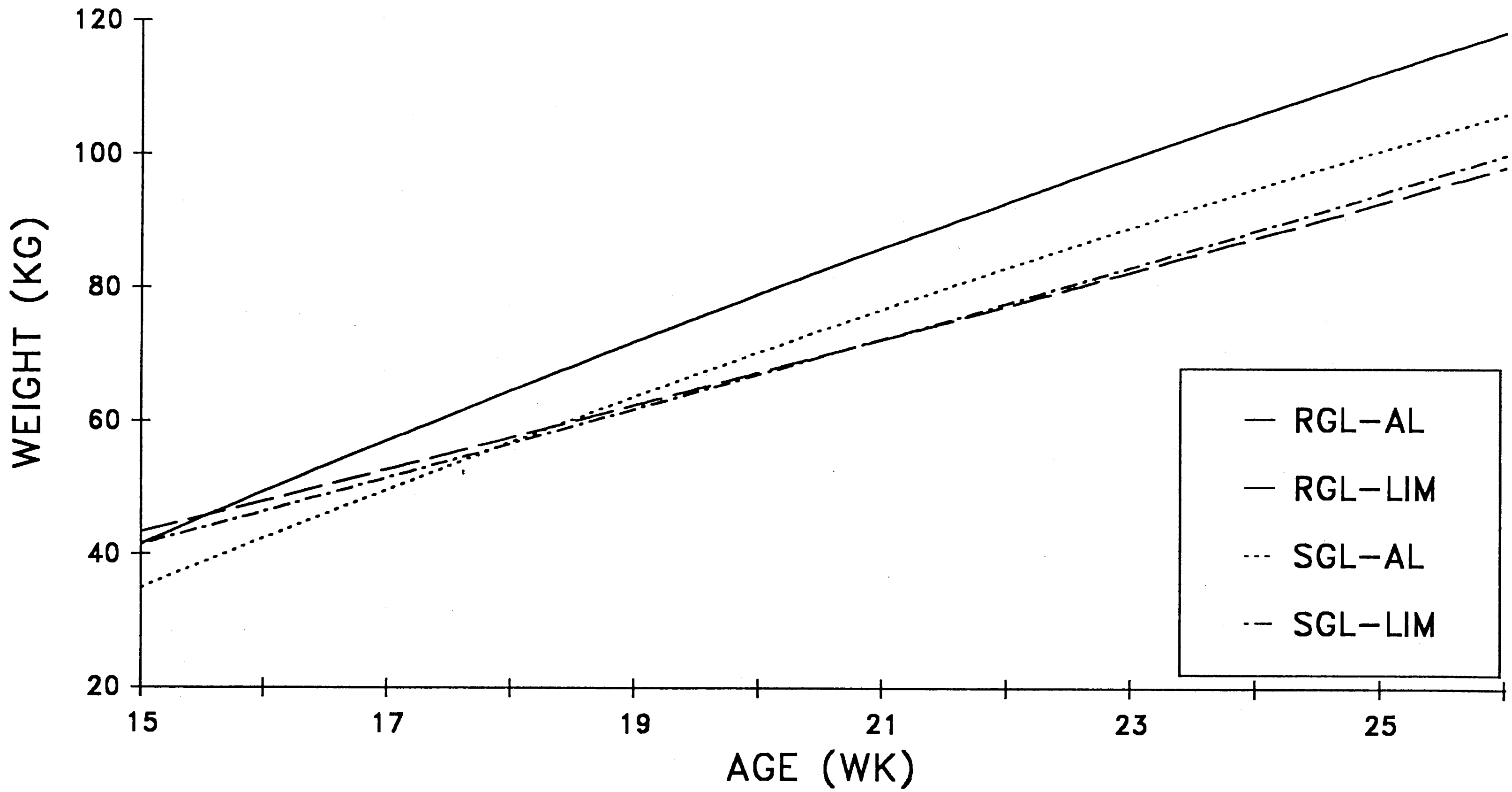

RGL-AL: $Weight = -40.55 + 5.725*wk + 0.0336*wk^2$
RGL-LIM: $Weight = -5.20 + 2.371*wk + 0.0905*wk^2$
SGL-AL: $Weight = -45.60 + 6.339*wk - 0.0246*wk^2$
SGL-LIM: $Weight = -7.27 + 2.362*wk + 0.0721*wk^2$

Figure 2. Regression of Weight on Age in Generation Three of the Spring Replicate




RGL-AL: Weight = $-42.66 + 6.417 * wk - 0.0003 * wk^2$
RGL-LIM: Weight = $-19.61 + 4.272 * wk + 0.0365 * wk^2$
SGL-AL: Weight = $-44.74 + 6.447 * wk - 0.0331 * wk^2$
SGL-LIM: Weight = $-31.92 + 5.049 * wk + 0.0015 * wk^2$

Figure 3. Regression of Weight on Age in Generation Four of the Spring Replicate




RGL–AL: Weight = $-97.62 + 10.603 * wk - 0.0884 * wk^2$

RGL–LIM: Weight = $-19.91 + 3.767 * wk - 0.0298 * wk^2$

SGL–AL: Weight = $-103.22 + 10.782 * wk - 0.1051 * wk^2$

SGL–LIM: Weight = $-25.53 + 3.978 * wk - 0.0326 * wk^2$

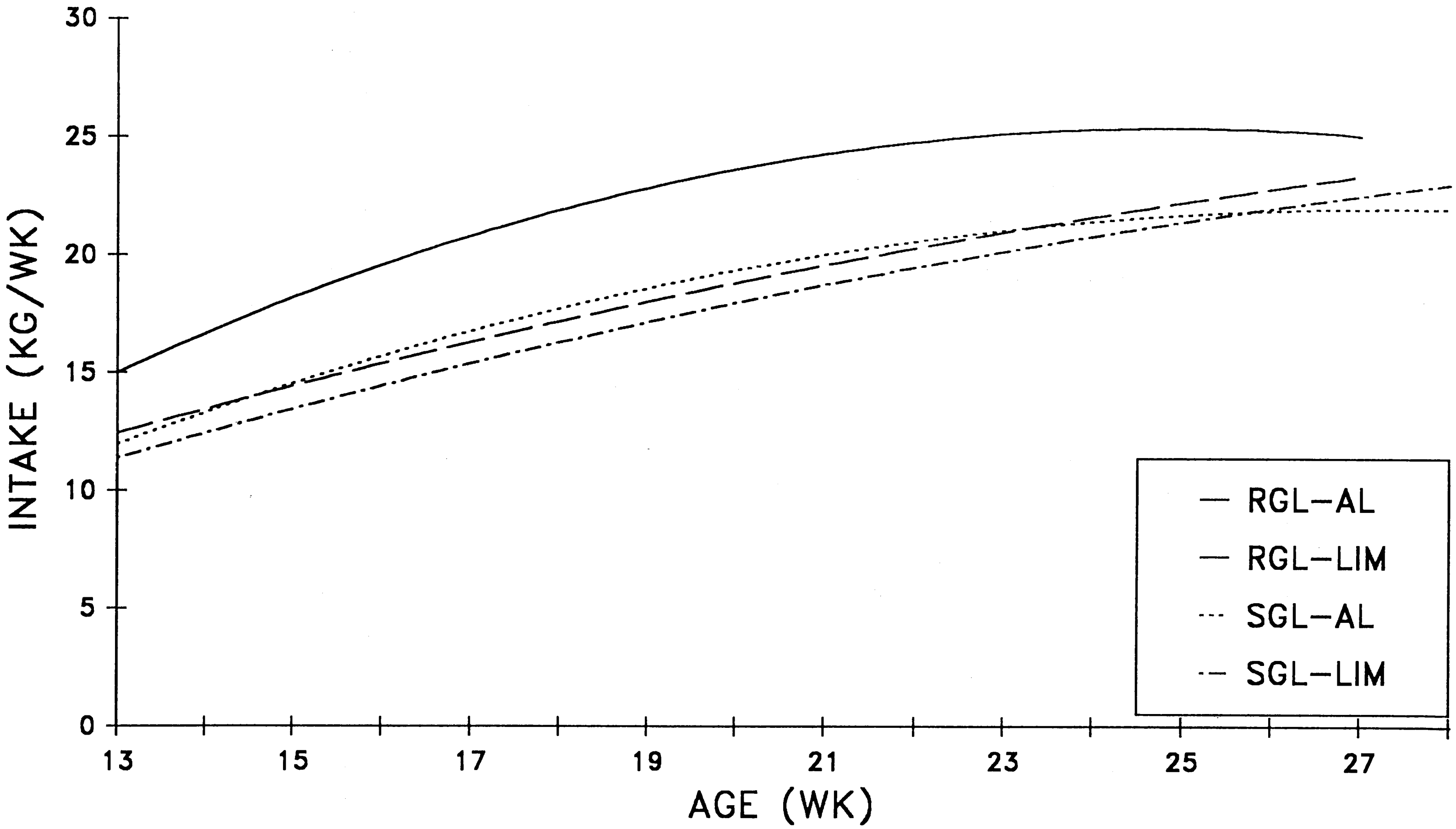
Figure 4. Regression of Weight on Age in the Fall Replicate

essentially linear in shape. Even though quadratic terms are fit for these data, they were not significant.

Regression of intake on age are presented in figure 5 and 6 and intake on BW in figure 7 and 8. The largest difference in consumption between the lines when fed AL tended to be at heavier wt (> 75 kg). Intake curves of the LIM pigs are very similar in shape, which agrees with daily intake means. In the spring replicate, LIM intakes appear to the be the same at a given wt, but higher at a given age in the RGL.

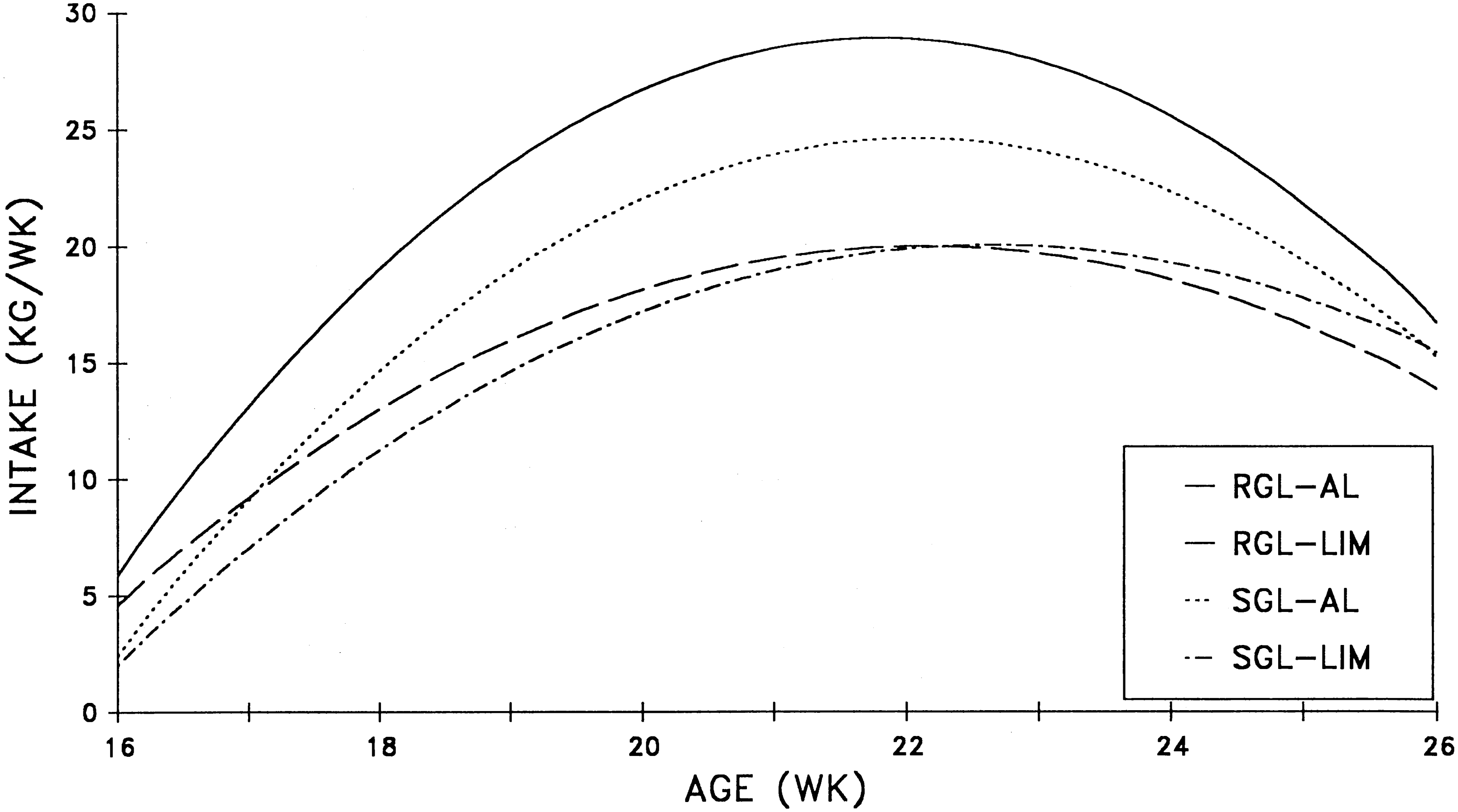
Curves representing the regression of gain on age (Figures 9 and 10) and gain on BW (Figures 11 and 12) indicate gain peaks at an earlier wt in the SGL when fed at either level of intake, even though age at peak gain appears to be similar for the two lines. In mice, growth curves of fast and control lines peaked near the same age, but at different wt (Timon and Eisen, 1969; Stainer and Mount, 1972). In the fall replicate the SGL-AL pigs reach a higher level of gain than spring replicate barrows; however, after reaching the peak gains fall rapidly.

Measurements of probed backfat (Tables VII and X) and carcass backfat (Tables XI and XII) all follow similar patterns, even though probed backfat tended to overestimate fat thickness at the shoulder in both replicates and underestimate fat thickness at the last lumbar vertebrae in the spring replicate. The interaction of line x level of intake was significant (P<.01) for average backfat in the spring replicate (Table XI). When fed AL the RGL was 13.6% fatter, while there were no line difference when the lines were fed LIM. Similar reductions were seen for each of the individual fat measurements. In the fall replicate, the RGL maintained a similar advantage in fat at both levels of intake (P<.05), while comparable reductions in carcass backfat were




RGL–AL: Intake = $-20.32 + 3.677*wk - 0.0740*wk^2$
RGL–LIM: Intake = $-4.39 + 1.542*wk - 0.0191*wk^2$
SGL–AL: Intake = $-14.48 + 2.669*wk - 0.0489*wk^2$
SGL–LIM: Intake = $-6.36 + 1.637*wk - 0.0212*wk^2$

Figure 5. Regression of Intake on Age in the Spring Replicate



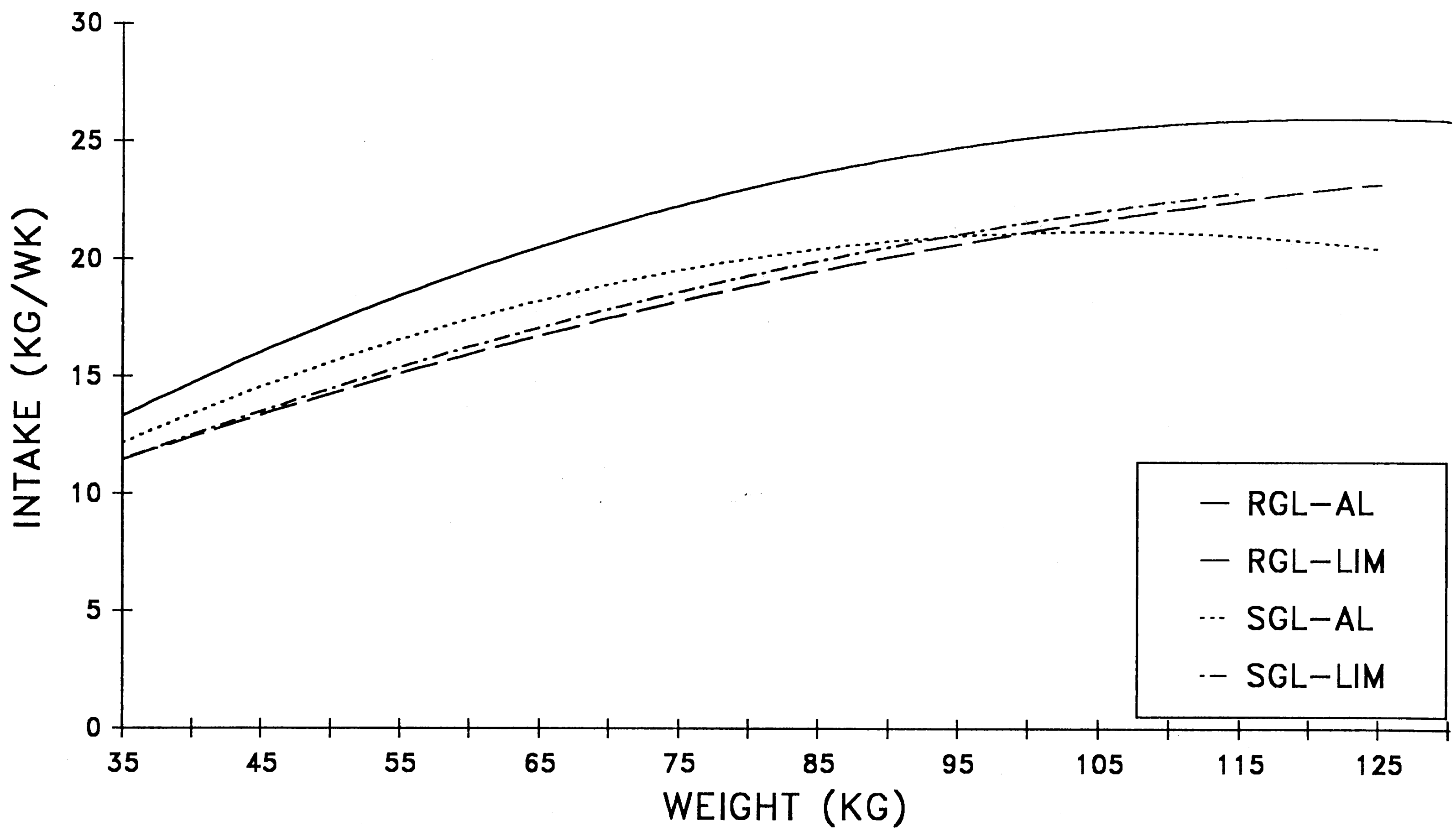

RGL-AL: $\text{Intake} = -297.41 + 29.949*wk - 0.6672*wk^2$

RGL-LIM: $\text{Intake} = -180.91 + 18.157*wk - 0.4103*wk^2$

SGL-AL: $\text{Intake} = -269.23 + 26.638*wk - 0.6037*wk^2$

SGL-LIM: $\text{Intake} = -189.57 + 18.521*wk - 0.4090*wk^2$

Figure 6. Regression of Intake on Age in the Fall Replicate



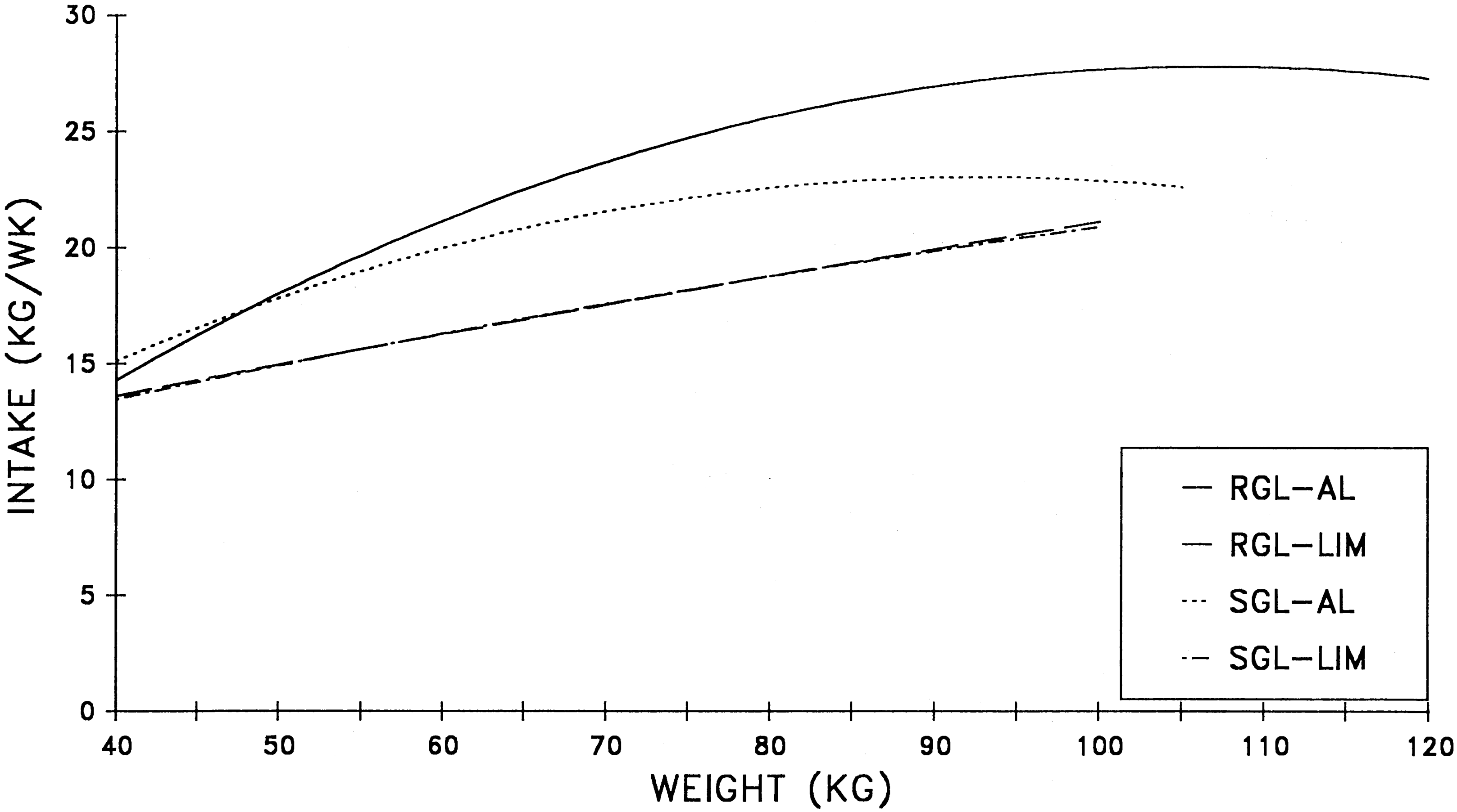

RGL–AL: Intake = $1.07 + 0.408*wt - 0.0017*wt^2$

RGL–LIM: Intake = $3.50 + 0.254*wt - 0.0008*wt^2$

SGL–AL: Intake = $0.88 + 0.386*wt - 0.0018*wt^2$

SGL–LIM: Intake = $2.77 + 0.280*wt - 0.0009*wt^2$

Figure 7. Regression of Intake on Weight in the Spring Replicate



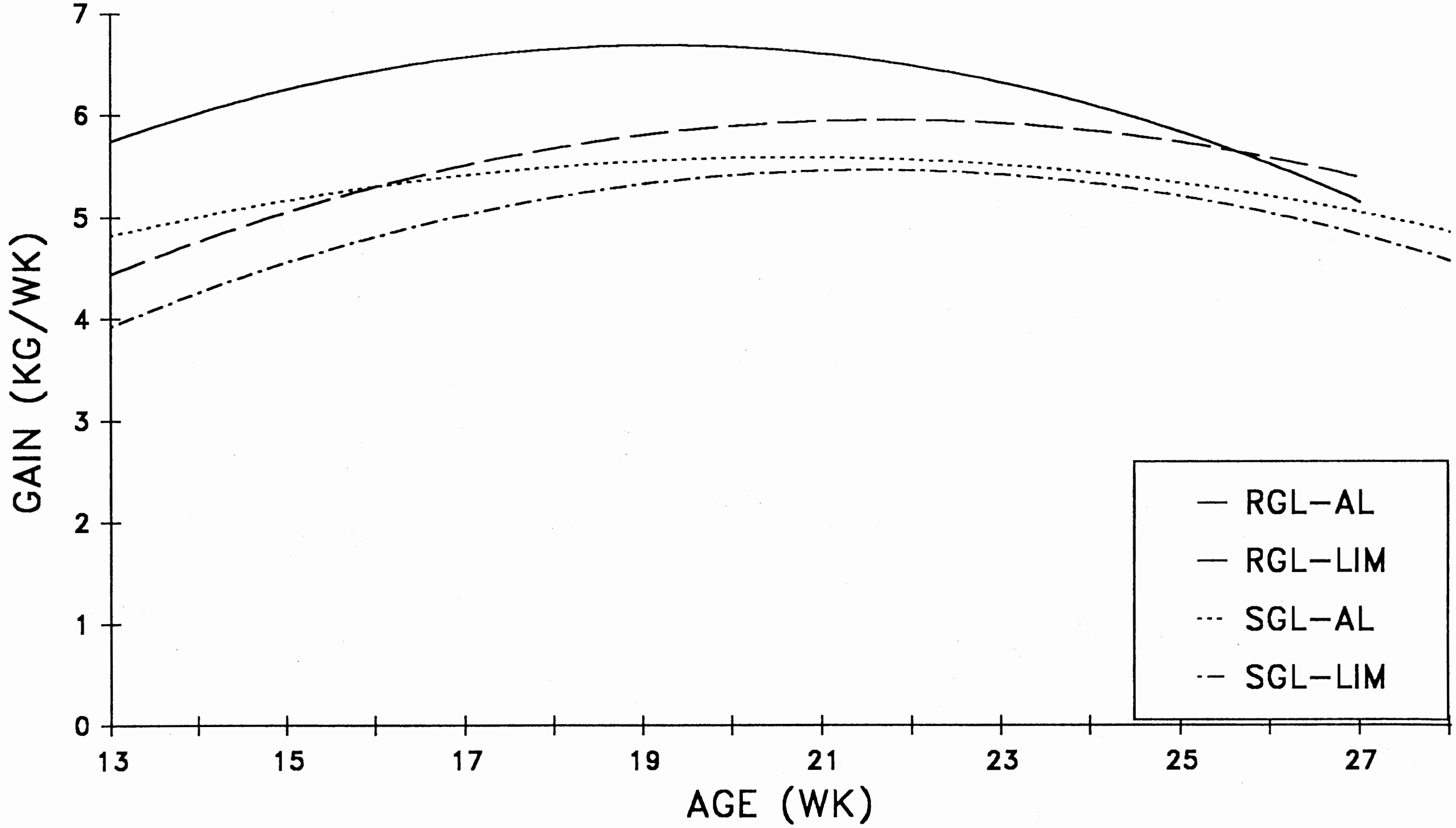

RGL-AL: Intake = $-6.76 + 0.647 * wt - 0.0030 * wt^2$

RGL-LIM: Intake = $7.80 + 0.153 * wt - 0.0002 * wt^2$

SGL-AL: Intake = $-1.52 + 0.530 * wt - 0.0029 * wt^2$

SGL-LIM: Intake = $6.75 + 0.185 * wt - 0.0004 * wt^2$

Figure 8. Regression of Intake on Weight in the Fall Replicate



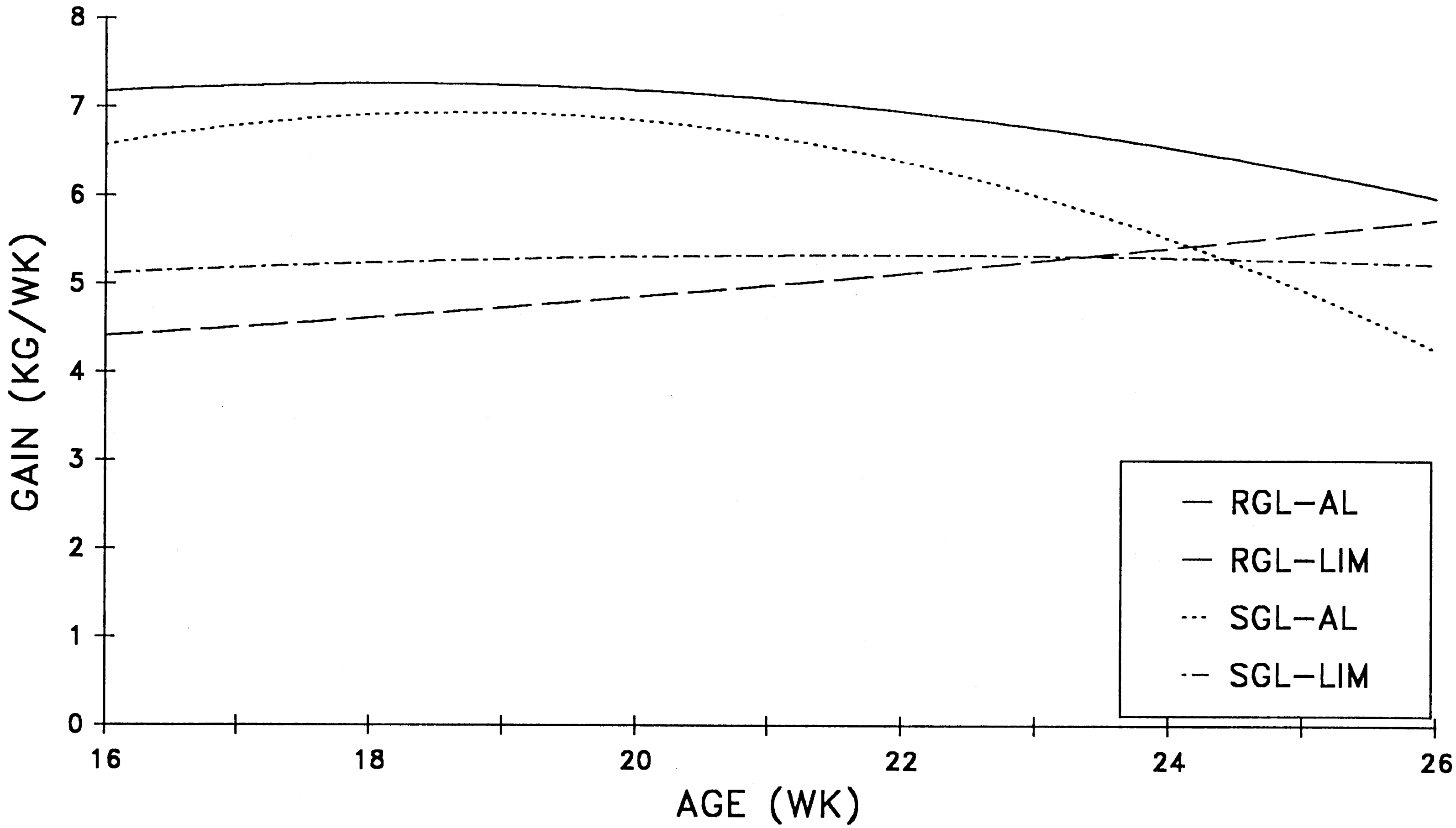

RGL–AL: $\text{Gain} = -2.49 + 0.958{*}\text{wk} - 0.0250{*}\text{wk}^2$

RGL–LIM: $\text{Gain} = -3.51 + 0.873{*}\text{wk} - 0.0201{*}\text{wk}^2$

SGL–AL: $\text{Gain} = -0.05 + 0.547{*}\text{wk} - 0.0133{*}\text{wk}^2$

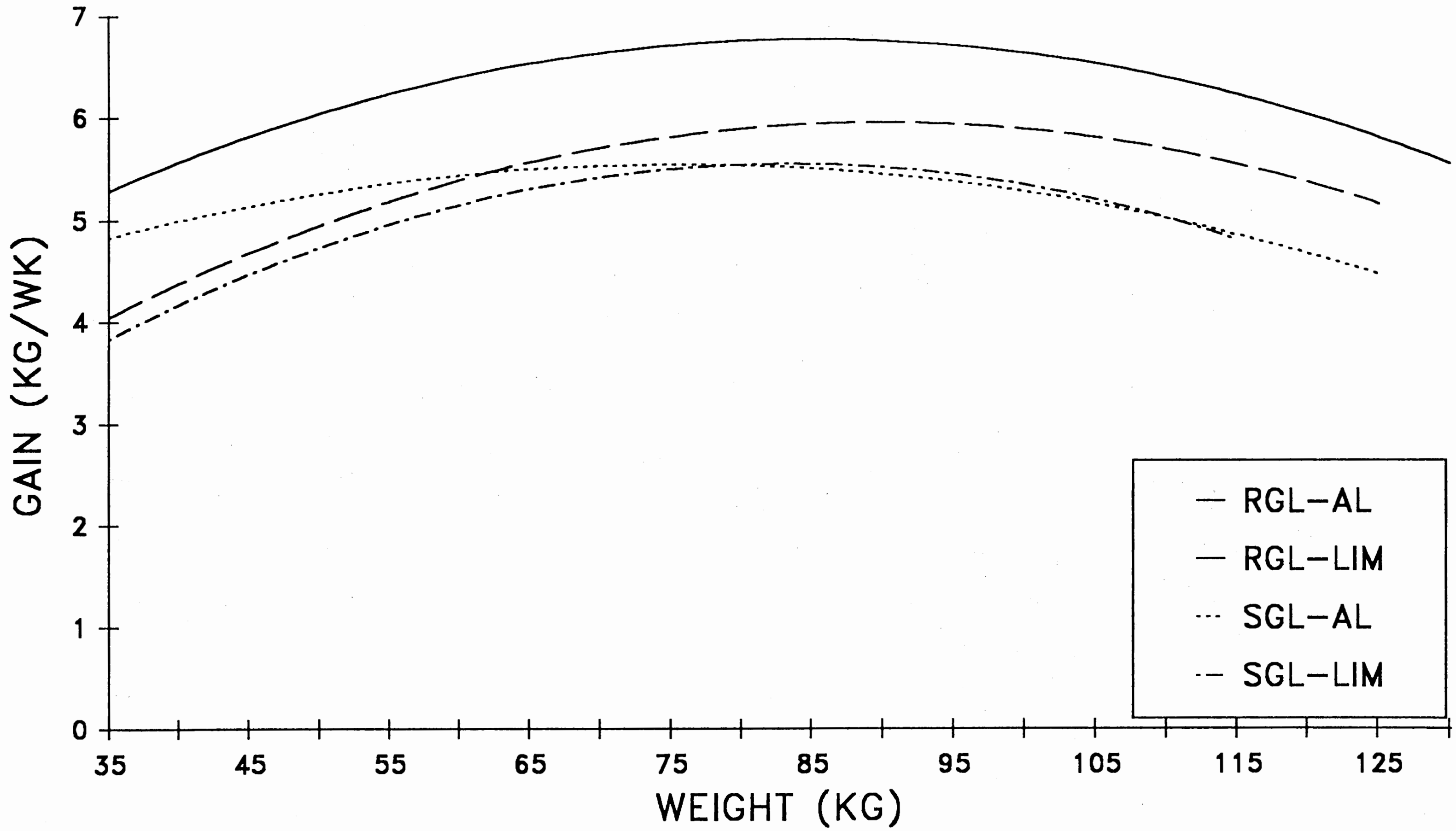
SGL–LIM: $\text{Gain} = -4.36 + 0.912{*}\text{wk} - 0.0.12{*}\text{wk}^2$

Figure 9. Regression of Gain on Age in the Spring Replicate



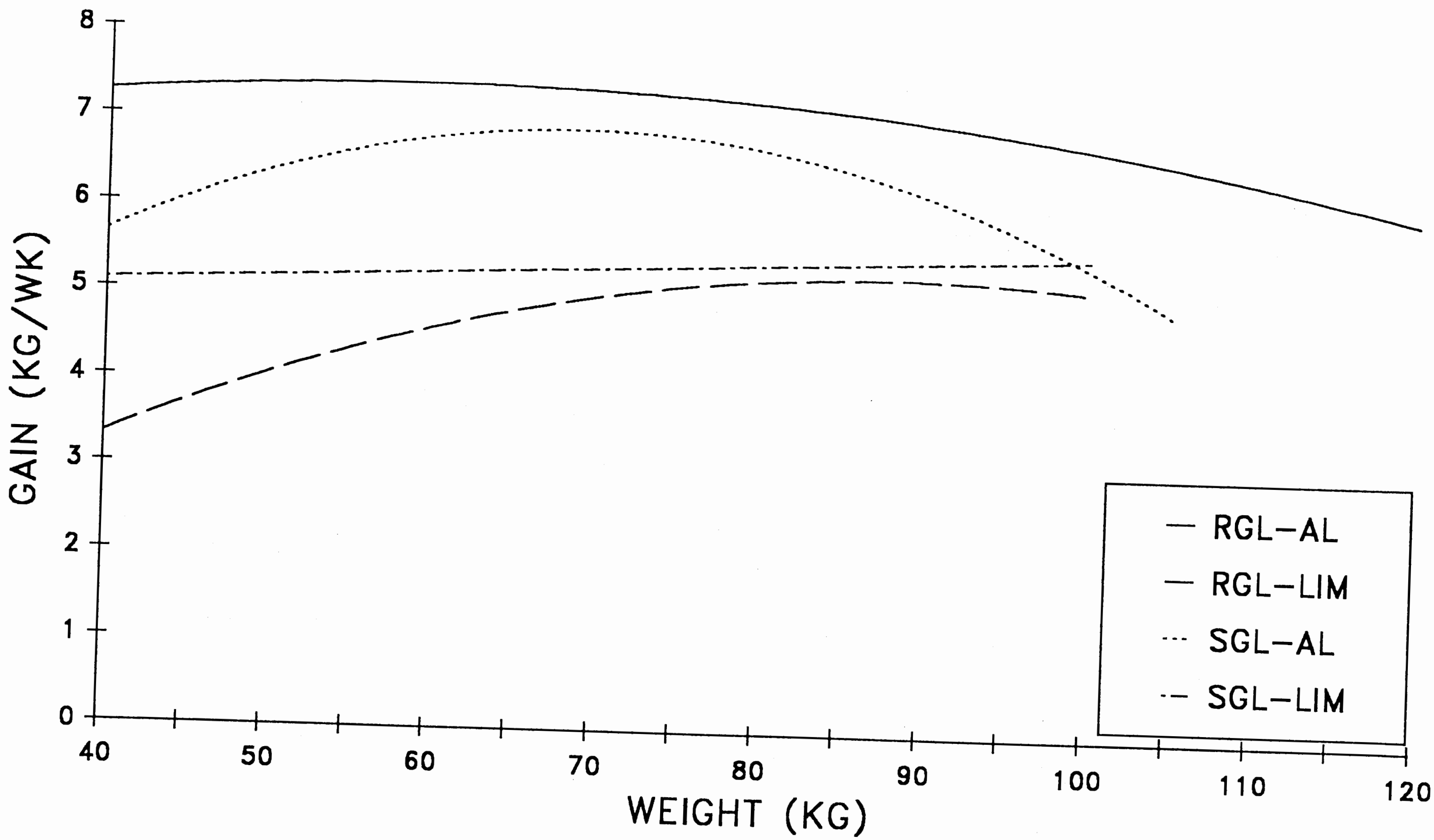

RGL-AL: Gain = $0.456 + 0.751*wk - 0.0207*wk^2$
RGL-LIM: Gain = $3.765 - 0.016*wk + 0.0035*wk^2$
SGL-AL: Gain = $-10.712 + 1.887*wk - 0.0504*wk^2$
SGL-LIM: Gain = $2.326 + 0.275*wk - 0.0063*wk^2$

Figure 10. Regression of Gain on Age in the Fall Replicate




RGL–AL: Gain = $2.54 + 0.102 * wt - 0.00060 * wt^2$
RGL–LIM: Gain = $0.81 + 0.115 * wt - 0.00064 * wt^2$
SGL–AL: Gain = $3.04 + 0.066 * wt - 0.00044 * wt^2$
SGL–LIM: Gain = $0.42 + 0.123 * wt - 0.00074 * wt^2$

Figure 11. Regression of Gain on Weight in the Spring Replicate




RGL–AL: Gain = $6.10 + 0.044*wt - 0.00037*wt^2$

RGL–LIM: Gain = $-1.20 + 0.146*wt - 0.00083*wt^2$

SGL–AL: Gain = $-0.24 + 0.208*wt - 0.00515*wt^2$

SGL–LIM: Gain = $4.79 + 0.008*wt - 0.000004*wt^2$

Figure 12. Regression of Gain on Weight in the Fall Replicate

TABLE XI

LEAST-SQUARES MEANS FOR CARCASS MEASUREMENTS IN THE SPRING REPLICATE

| Line[a] | RGL | | SGL | | |
|---|---|---|---|---|---|
| Level of intake[a] | AL | LIM | AL | LIM | SE |
| Slaughter wt, kg | 116.1 | 108.0 | 103.1 | 100.6** | 1.02 |
| Loin eye area[b], $cm^2$ | 30.5 | 30.7 | 27.9 | 26.7 | .01 |
| Carcass length[bc], cm | 82.8 | 81.3 | 79.2 | 78.2 | .07 |
| Average backfat[d] | 3.23 | 2.64 | 2.79 | 2.67** | .01 |
| Backfat shoulder[d] | 4.11 | 3.61 | 3.78 | 3.63+ | .02 |
| Backfat last rib[d] | 2.54 | 1.96 | 2.13 | 2.01** | .01 |
| Backfat last lumbar[d] | 2.97 | 2.34 | 2.46 | 2.39** | .01 |

**Significant line x level of intake interaction ($P < .01$).
+Significant line x level of intake interaction ($P < .10$).
[a]RGL = rapid growth line, SGL = slow growth line, AL = ad libitum, LIM = limited to 83 % of predicted ad libitum.
[b]Line means differ ($P < .05$).
[c]Level of intake means differ ($P < .05$).
[d]Carcass backfat in cm.

TABLE XII

LEAST-SQUARES MEANS FOR CARCASS MEASUREMENTS IN THE FALL REPLICATE

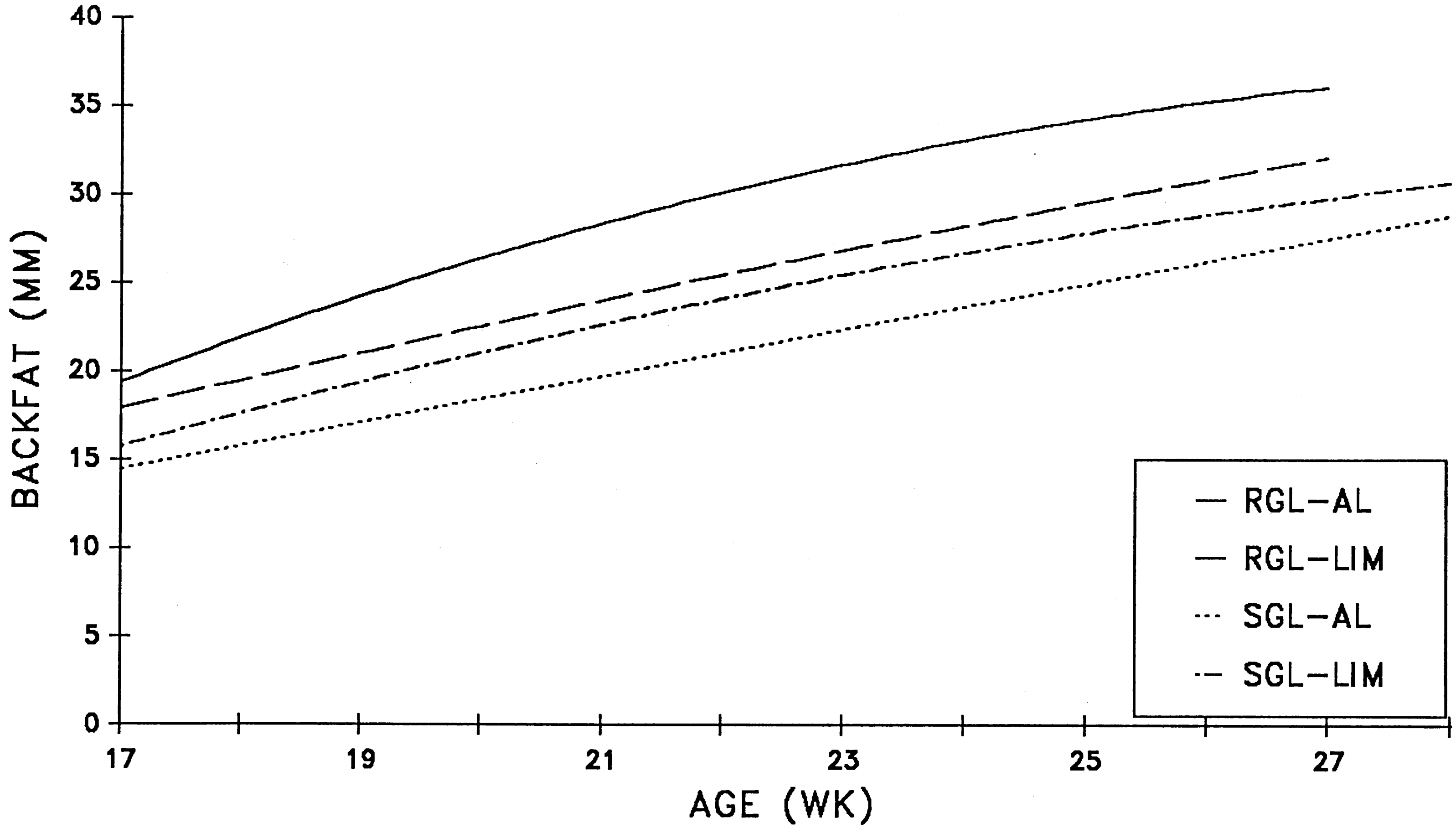
| Line[a] | RGL | | SGL | | |
|---|---|---|---|---|---|
| Level of intake[a] | AL | LIM | AL | LIM | SE |
| Slaughter wt, kg | 109.4 | 91.6 | 99.9 | 91.7** | 2.05 |
| Loin eye area[c], $cm^2$ | 28.8 | 25.1 | 29.7 | 26.3 | 0.02 |
| Carcass length[c], cm | 80.3 | 76.5 | 79.5 | 77.7 | 0.10 |
| Average backfat[bcd] | 3.15 | 2.59 | 2.69 | 2.21 | 0.02 |
| Backfat shoulder[bcd] | 4.24 | 3.71 | 3.66 | 3.50 | 0.02 |
| Backfat last rib[bcd] | 2.59 | 2.08 | 2.21 | 1.80 | 0.02 |
| Backfat last lumbar[bcd] | 2.64 | 2.01 | 2.24 | 1.70 | 0.02 |

*Significant line x level of intake interaction ($P < .05$).
[a]RGL = rapid growth line, SGL = slow growth line, AL = ad libitum, LIM = limited to 83 % of predicted ad libitum.
[b]Line means differ ($P < .05$).
[c]Level of intake means differ ($P < .05$).
[d]Carcass backfat in cm.

seen in each line when fed LIM (Table XII). In both replicates the differences in backfat (AL vs LIM, RGL vs SGL) correspond closely with the differences in feed intake.

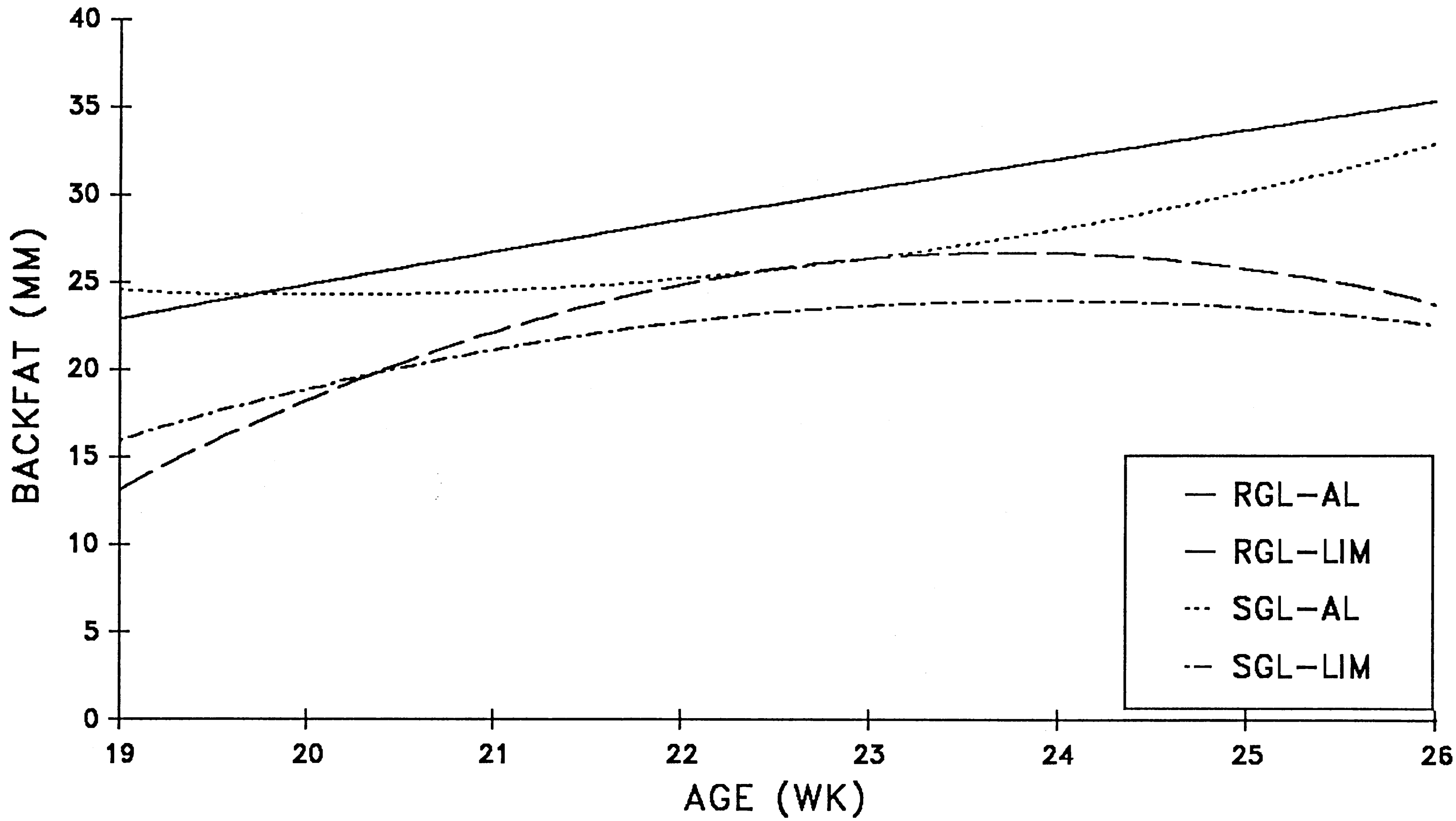
Correlated increases in fat at a given age and/or wt were reported in reviews of selection for increased growth in mice (Roberts, 1979; McCarthy, 1980; Malik, 1984), while it appears downward selection for growth decreases the proportion of fat (McCarthy, 1980). In Duroc swine selected four generations for increased 200-day weight, carcass fat increased at 105 kg (Jungst and Kuhlers, 1987) and probed backfat at 200 d increased .07 cm/generation (Kuhlers and Jungst, 1987). Selection for increased 200-day weight in the Landrace breed decreased carcass backfat at 100 kg (Kuhlers and Jungst, 1986). Selection for maximum postweaning growth for nine generations resulted in a significant decrease in carcass backfat and an increase in predicted lean yield ( 9.8 and 1.4%, respectively) (Fredeen and Mikami, 1986).

The regressions of backfat on age and BW are shown in figures 13 and 14 and figures 15 and 16, respectively. At a given age in the spring, RGL-AL pigs are fatter while at a given weight very few differences are seen. This indicates fat differences at off-test weight may be in large part due to weight differences within each line-level of intake subclass. As was the case for weight curves, Robison (1974) suggested the regression of backfat on either age or weight is essentially linear. These data suggest differences in growth rate or intake do not appear to change the shape of the curve appreciably. The fall replicate gives no clear indications of fat deposition over age or weight. This is probably due to a number of reasons: the small number of pigs in the fall replicate, the relatively small number of



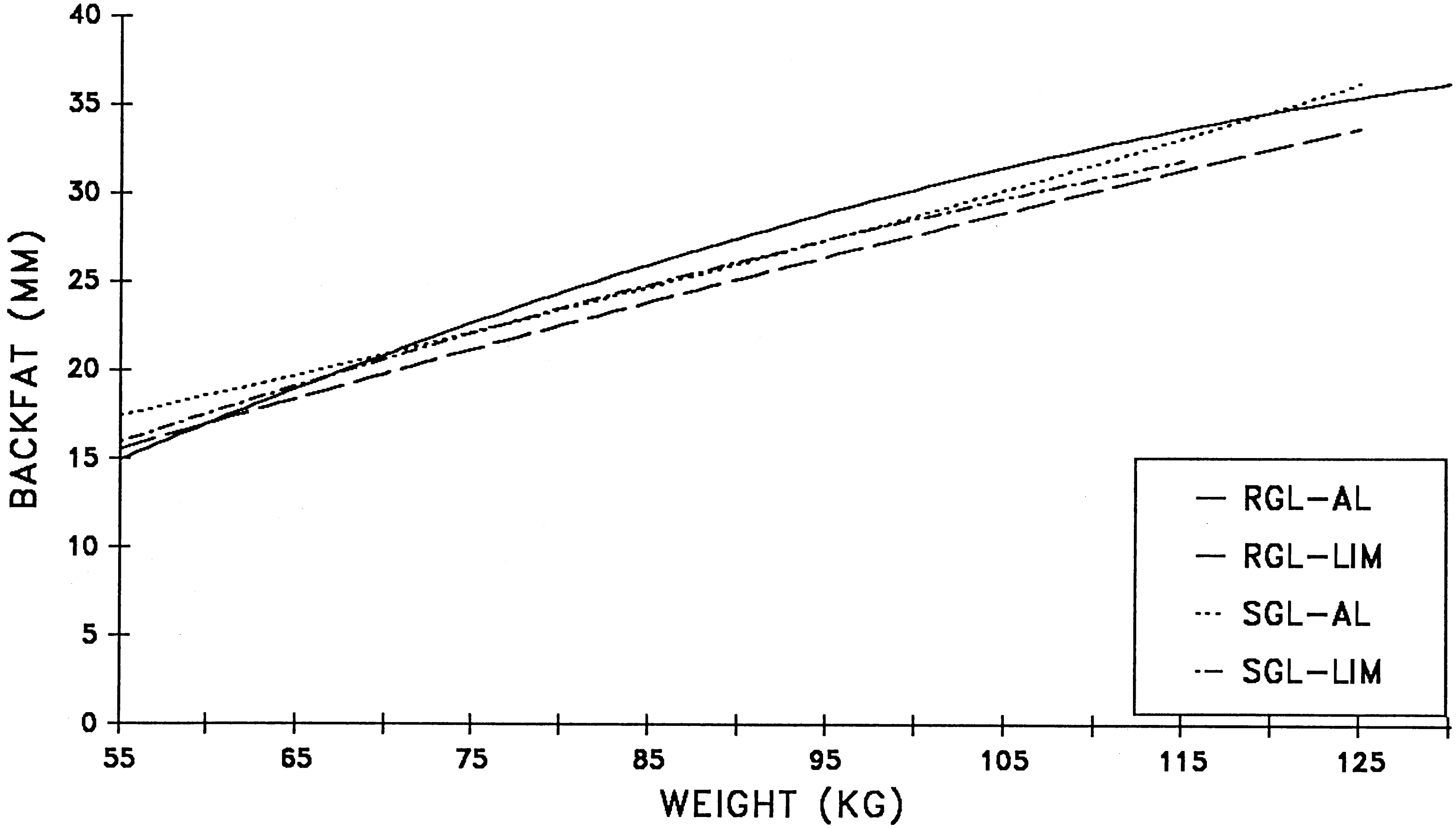

RGL-AL: Backfat = $-53.33 + 5.919 * wk - 0.0966 * wk^2$
RGL-LIM: Backfat = $-14.42 + 2.206 * wk - 0.0178 * wk^2$
SGL-AL: Backfat = $-9.48 + 1.470 * wk - 0.0292 * wk^2$
SGL-LIM: Backfat = $-32.65 + 3.755 * wk - 0.0467 * wk^2$

Figure 13. Regression of Backfat on Age in the Spring Replicate




RGL-AL: Backfat = $-26.435 + 3.199 * wk - 0.0317 * wk^2$
RGL-LIM: Backfat = $-312.384 + 28.541 * wk - 0.6005 * wk^2$
SGL-AL: Backfat = $122.186 - 9.762 * wk + 0.2434 * wk^2$
SGL-LIM: Backfat = $-165.232 + 15.820 * wk - 0.3307 * wk^2$

Figure 14. Regression of Backfat on Age in the Fall Replicate



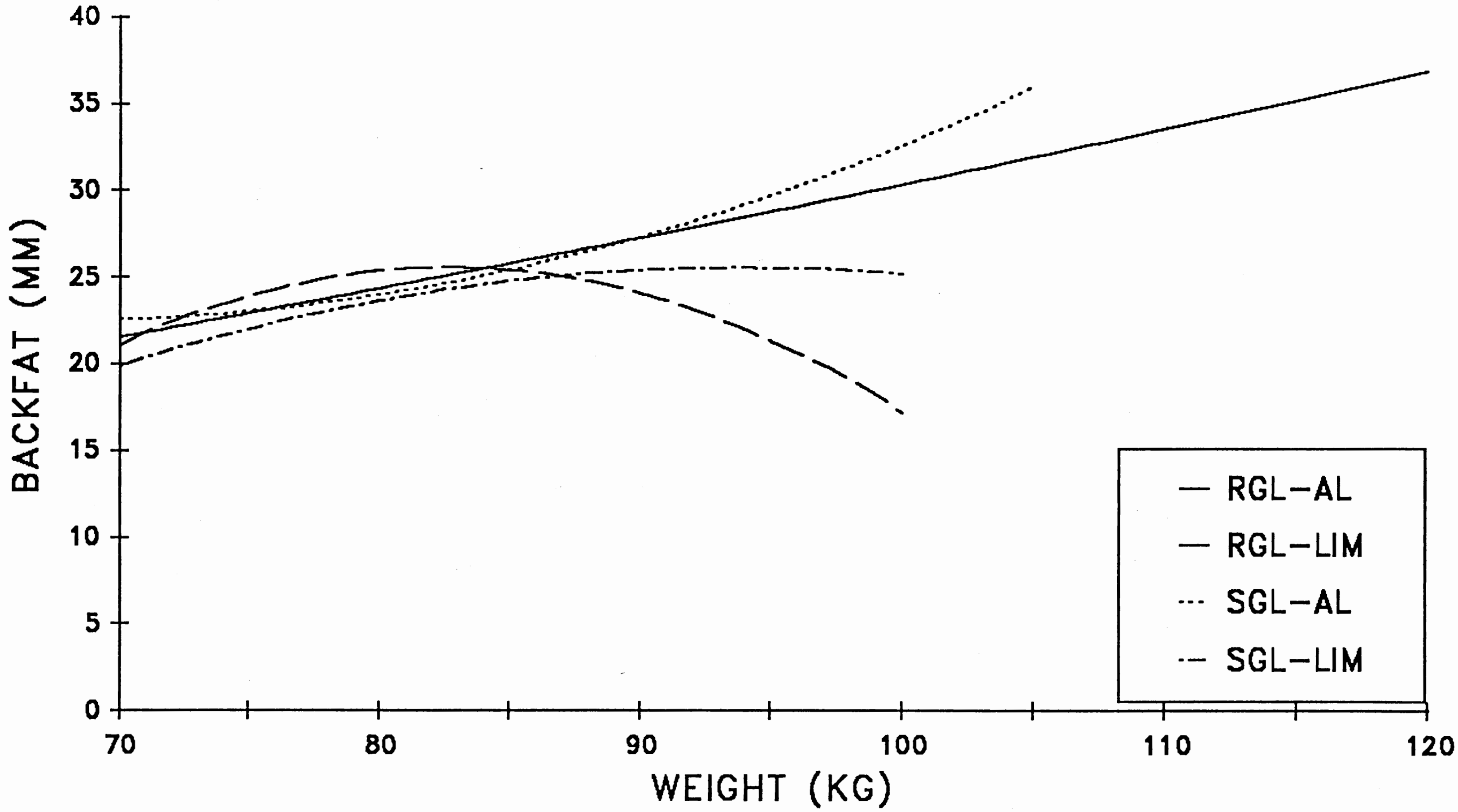

RGL-AL: Backfat = $-14.46 + 0.640 \cdot wt - 0.0019 \cdot wt^2$

RGL-LIM: Backfat = $-1.89 + 0.342 \cdot wt - 0.0005 \cdot wt^2$

SGL-AL: Backfat = $6.95 + 0.157 \cdot wt - 0.0006 \cdot wt^2$

SGL-LIM: Backfat = $-5.52 + 0.450 \cdot wt - 0.0011 \cdot wt^2$

Figure 15. Regression of Backfat on Weight in the Spring Replicate




RGL-AL: Backfat = $5.04 + 0.195*wt + 0.0006*wt^2$

RGL-LIM: Backfat = $-166.50 + 4.644*wt - 0.0281*wt^2$

SGL-AL: Backfat = $66.03 - 1.289*wt + 0.0096*wt^2$

SGL-LIM: Backfat = $62.73 + 1.882*wt - 0.0100*wt^2$

Figure 16. Regression of Backfat on Weight in the Fall Replicate

observations per pig as compared to intake and gain, and the error involved in measuring backfat. In addition, very few observations occur at the extremes of the age or weight range. This is true for the all regressions, especially those in the fall replicate.

Means for percent ether extract and moisture for the semitendinosus and biceps femoris muscles are given in tables XIII and XIV for the spring and fall replicates, respectively. No consistent differences are seen. Similarly, no differences were seen in percent ether extract or moisture of the total dissected lean (Tables XV and XVI).

Dissected lean, fat and bone means expressed as absolute weight and a percentage of carcass weight are given for the spring and fall replicates in tables XV and XVI, respectively. Line x level of intake interactions in the spring ($P<.01$) for percent lean and fat and total fat are closely associated with intake levels and carcass backfat. The RGL-AL had 2.4% less lean and 3.0% more fat than the SGL-AL, while there were no differences between lines on LIM. Line differences were seen for total dissected lean ($P<.05$), which were mostly due to differences in slaughter weight. Line differences were also seen in loin eye area (Table XI), which corresponds to differences in weight of dissected lean. The RGL-AL pigs had 25% more dissected fat than the SGL-AL and 28% more than the RGL-LIM, while only small, non-significant line differences at the limited intake level. This indicates additional intake by the RGL is utilized mainly for the deposition of fat. Bone remained relatively constant. Like lean, line difference for total bone can be attributed to slaughter weight.

In the fall replicate, the line x level of intake interaction tended to be significant for percent dissected lean ($P<.10$). Subclass

TABLE XIII

LEAST-SQUARES MEANS FOR PERCENT ETHER EXTRACT AND MOISTURE FROM THE SEMITENDENOSIS AND BICEPS FEMORIS MUSCLES IN THE SPRING REPLICATE

| Line[a] | RGL | | SGL | | |
|---|---|---|---|---|---|
| Level of intake[a] | AL | LIM | AL | LIM | SE |
| Ether extract, ST | 7.2 | 7.4 | 7.4 | 8.0 | .45 |
| Moisture, ST[b] | 72.3 | 72.5 | 71.7 | 71.5 | .39 |
| Ether extract, BF | 7.2 | 6.7 | 7.0 | 7.0 | .27 |
| Moisture, BF | 71.5 | 72.3 | 71.6 | 71.4+ | .24 |

+Significant line x level of intake interaction (P < .10).
[a]RGL = rapid growth line, SGL = slow growth line, AL = ad libitum, LIM = limited to 83 % of predicted ad libitum.
[b]Line means differ (P < .05).
ST=semitendenosis muscle.
BF=biceps femoris muscle.

TABLE XIV

LEAST-SQUARES MEANS FOR PERCENT ETHER EXTRACT AND MOISTURE FROM THE SEMITENDENOSIS AND BICEPS FEMORIS MUSCLES IN THE FALL REPLICATE

| Line[a] | RGL | | SGL | |
|---|---|---|---|---|
| Level of intake[a] | AL | LIM | AL | LIM |
| Ether extract, ST[b] | 7.3<br>(.51)[c] | 6.7<br>(.51) | 8.6<br>(.51) | 6.5<br>(.54) |
| Moisture, ST | 72.2<br>(.42) | 72.6<br>(.42) | 71.1<br>(.42) | 73.4*<br>(.45) |
| Ether Extract, BF | 6.3<br>(.53) | 6.6<br>(.53) | 6.7<br>(.53) | 6.3<br>(.56) |
| Moisture, BF | 72.2<br>(.45) | 72.4<br>(.45) | 71.5<br>(.45) | 72.8<br>(.48) |

*Significant line x level of intake interaction (P < .05).
[a]RGL = rapid growth line, SGL = slow growth line, AL = ad libitum, LIM = limited to 83 % of predicted ad libitum.
[b]Level of intake means differ (P < .05).
[c]Standard errors
ST=semitendenosis muscle.
BF=biceps femoris muscle.

TABLE XV

LEAST-SQUARES MEANS FOR CARCASS COMPOSITION IN THE SPRING REPLICATE

| Line[a] | RGL | | SGL | | |
|---|---|---|---|---|---|
| Level of intake[a] | AL | LIM | AL | LIM | SE |
| Percent lean[c] | 59.9 | 63.4 | 62.3 | 62.6** | .59 |
| Percent fat[c] | 28.8 | 24.5 | 25.8 | 25.6** | .66 |
| Percent bone[c] | 11.3 | 12.2 | 11.9 | 11.9* | .21 |
| Total lean[bd] | 22.6 | 22.0 | 20.9 | 20.3 | .32 |
| Total fat[d] | 10.9 | 8.5 | 8.7 | 8.3** | .26 |
| Total bone[bd] | 4.3 | 4.2 | 4.0 | 3.9 | .07 |
| Ether extract, % | 20.5 | 20.1 | 19.9 | 19.7 | .38 |
| Fat-free lean[e], % | 47.6 | 50.7 | 49.9 | 50.3* | .60 |
| Moisture, % | 61.0 | 61.8 | 61.7 | 61.7 | .29 |

**Significant line x level of intake interaction ($P < .01$).
*Significant line x level of intake interaction ($P < .05$).
[a]RGL = Rapid growth line, SGL = slow growth line, AL = ad libitum, LIM = limited to 83 % of predicted ad libitum.
[b]Line means differ ($P < .05$).
[c]Expressed as a percentage of chilled carcass weight.
[d]Right side of the chilled carcass (kg).
[e]Total lean - (total lean x ether extract).

TABLE XVI

LEAST-SQUARES MEANS FOR CARCASS COMPOSITION IN THE FALL REPLICATE

| Line[a] | RGL | | SGL | | |
|---|---|---|---|---|---|
| Level of intake[a] | AL | LIM | AL | LIM | SE |
| Percent lean[b] | 55.9 | 61.5 | 61.2 | 62.1+ | 1.20 |
| Percent fat[bcd] | 33.1 | 26.5 | 26.8 | 24.6 | 1.32 |
| Percent bone[bcd] | 10.9 | 12.0 | 12.0 | 13.3 | 0.37 |
| Total lean[ce] | 20.5 | 18.1 | 20.2 | 18.5 | 0.59 |
| Total fat[e] | 12.1 | 7.8 | 8.9 | 7.3** | 0.48 |
| Total bone[e] | 4.0 | 3.5 | 4.0 | 3.9 | 0.14 |
| Ether extract, % | 17.9 | 17.8 | 16.9 | 14.1 | 1.19 |
| Fat-free lean[bcf], % | 45.9 | 50.6 | 50.9 | 53.4 | 1.32 |
| Moisture, % | 62.7 | 62.4 | 62.6 | 68.4 | 2.07 |

**Significant line x level of intake interaction (P < .01).
+Significant line x level of intake interaction (P < .10).
[a]RGL = rapid growth line, SGL = slow growth line, AL = ad libitum, LIM = limited to 83 % of predicted ad libitum.
[b]Line means differ (P < .05).
[c]Level of intake means differ (P < .05).
[d]Expressed as a percentage of chilled carcass weight.
[e]Right side of the chilled carcass (kg).
[f]Total lean - (total lean x ether extract).

means for percent dissected fat reacted in the same manner as seen in the spring, but the interaction of line x level of intake was non-significant (P>.10). Level of intake had a significant affect on deposition of lean (P<.05), which is in opposition to the spring replicate where only line was significant (P<.05). This again relates to both lines being restricted by a greater percentage than designed in the fall. As was seen for total lean, level of intake had a significant affect on loin eye area (P<.05) (Table XII). Estimates of percent fat-free lean were closely related to percent dissected lean in both seasons. This is due to no differences found in the ether extract of lean tissue.

Kuhlers and Jungst (1986) reported correlated increases in loin eye area and percent lean cuts at 100 kg in Landrace selected for increased 200-day weight. However, in a Duroc line selected for the same trait percent lean cuts decreased (Jungst and Kuhlers, 1987). Protein gain was decreased by 20% when an index line selected for increased growth and decreased backfat was restricted to 82% of ad libitum, with a 13% decrease seen in a control line (Cleveland et al., 1983). Restriction was started near 25 kg and it was estimated that the index and control lines on the restricted level of intake were only consuming 88 and 93% of required protein, respectively. Bichard et al. (1979) suggested during early stages of growth (< 35 kg) pigs should be allowed to consume at or near ad libitum to allow for maximum lean growth to be displayed. Restriction at 80% of ad libitum reduced gain by 20% and protein deposition by 8% when fed to a common age (Metz et al., 1980). Just and Pedersen (1976) found lean deposition to be only slightly affected by feeding intensity, provided the essential energy and nutrients are provided.

Means for total dissected lean, fat and bone from each of the four major cuts are given in tables XVII and XIX and on a percentage of carcass basis in tables XVIII and XX. Line x level of intake interactions were significant in the spring replicate ($P<.05$) for all measurements of total dissected fat, except for the shoulder. Limit-fed pigs had similar fat wt across lines, while RGL-AL pigs had 19, 32, 13 and 30% more fat than SGL-AL in the ham, loin, shoulder and belly, respectively. Kempster and Evans (1979) found relative rates of fat deposition were lowest in the ham and highest in the back, while Doornenbal (1972) found the rate of fat deposition to be nearly twice as high in the loin region. It appears additional intake in the RGL is utilized to a greater extend for the deposition of fat in the loin and belly.

Line was significant for lean weight from all four carcass regions ($P<.05$), with only small differences due to level of intake. However, on a percentage basis most of the decrease in percent lean in the RGL-AL was due to decreases in the ham and shoulder. Richmond and Berg (1971) found plane of nutrition had little affect on muscle distribution. This appears to be true on a weight basis, but not when expressed as a percentage of carcass weight. Increased percent fat in the RGL-AL is the result of correlated increased in the ham, loin and belly, with little change in the shoulder.

In the fall replicate limit feeding affected growth of all tissues in the RGL (fat > lean > bone) and fat and lean in the SGL (fat > lean), with more severe reductions in the RGL. This probably relates to the

TABLE XVII

LEAST-SQUARES MEANS FOR WEIGHTS OF THE MAJOR WHOLESALE CUTS IN THE SPRING REPLICATE[a]

| Line[b] | RGL | | SGL | | |
|---|---|---|---|---|---|
| Level of intake[b] | AL | LIM | AL | LIM | SE |
| Lean ham[c] | 6.19 | 6.09 | 5.72 | 5.51 | .09 |
| Fat ham | 2.50 | 2.05 | 2.10 | 2.04** | .05 |
| Bone ham[c] | 1.01 | 1.01 | 0.97 | 0.90 | .02 |
| Lean loin[cd] | 5.76 | 5.49 | 5.12 | 4.92 | .10 |
| Fat loin | 3.71 | 2.77 | 2.82 | 2.75** | .11 |
| Bone loin[c] | 1.41 | 1.33 | 1.23 | 1.25 | .04 |
| Lean shoulder[c] | 6.20 | 6.16 | 5.91 | 5.81 | .11 |
| Fat shoulder[cd] | 1.99 | 1.71 | 1.76 | 1.68 | .06 |
| Bone shoulder[c] | 1.32 | 1.33 | 1.26 | 1.25 | .03 |
| Lean belly[c] | 4.50 | 4.28 | 4.21 | 4.05 | .10 |
| Fat belly | 2.68 | 2.00 | 2.06 | 1.85* | .10 |
| Bone belly | 0.53 | 0.54 | 0.52 | 0.46* | .02 |

**Significant line x level of intake interaction ($P < .01$).
*Significant line x level of intake interaction ($P < .05$).
[a]Right side chilled carcass weight (kg).
[b]RGL = rapid growth line, SGL = slow growth line, AL = ad libitum, LIM = limited to 83 % of predicted ad libitum.
[c]Line means differ ($P < .05$).
[d]Level of intake means differ ($P < .05$).

TABLE XVIII

LEAST-SQUARES MEANS FOR THE PERCENT COMPOSITION OF THE MAJOR WHOLESALE CUTS IN THE SPRING REPLICATE[a]

| Line[b] | RGL | | SGL | | |
|---|---|---|---|---|---|
| Level of intake[b] | AL | LIM | AL | LIM | SE |
| Lean ham | 16.4 | 17.5 | 17.0 | 17.0** | .47 |
| Fat ham | 6.6 | 5.9 | 6.2 | 6.3** | .29 |
| Bone ham | 2.7 | 2.9 | 2.9 | 2.8* | .10 |
| Lean loin | 15.2 | 15.8 | 15.3 | 15.2 | .36 |
| Fat loin | 9.8 | 7.9 | 8.3 | 8.4** | .49 |
| Bone loin | 3.7 | 3.8 | 3.7 | 3.8 | .12 |
| Lean shoulder | 16.4 | 17.7 | 17.6 | 17.9* | .50 |
| Fat shoulder | 5.3 | 4.9 | 5.2 | 5.2 | .35 |
| Bone shoulder[c] | 3.5 | 3.8 | 3.8 | 3.8 | .09 |
| Lean belly | 11.9 | 12.3 | 12.4 | 12.5 | .64 |
| Fat belly | 7.1 | 5.7 | 6.1 | 5.7+ | .73 |
| Bone belly | 1.4 | 1.6 | 1.5 | 1.4** | .22 |

**Significant line x level of intake interaction ($P < .01$).
*Significant line x level of intake interaction ($P < .05$).
+Significant line x level of intake interaction ($P < .10$).
[a]Right side chilled carcass weight (kg).
[b]RGL = rapid growth line, SGL = slow growth line, AL = ad libitum, LIM = limited to 83 % of predicted ad libitum.
[c]Level of intake means differ ($P < .05$).

TABLE XIX

LEAST-SQUARES MEANS FOR WEIGHTS OF THE MAJOR WHOLESALE CUTS IN THE FALL REPLICATE[a]

| Line[b] | RGL | | SGL | | |
|---|---|---|---|---|---|
| Level of intake[b] | AL | LIM | AL | LIM | SE |
| Lean ham | 5.44 | 5.00 | 5.43 | 5.39 | .18 |
| Fat ham | 2.36 | 1.77 | 1.94 | 1.76+ | .10 |
| Bone ham | 0.89 | 0.72 | 0.89 | 0.87* | .03 |
| Lean loin[d] | 5.37 | 4.51 | 5.07 | 4.48 | .16 |
| Fat loin[cd] | 3.91 | 2.43 | 2.86 | 1.98 | .19 |
| Bone loin | 1.26 | 1.12 | 1.22 | 1.22+ | .04 |
| Lean shoulder[d] | 5.66 | 5.13 | 5.97 | 5.38 | .18 |
| Fat shoulder | 2.91 | 1.86 | 2.13 | 1.80** | .12 |
| Bone shoulder | 1.28 | 1.13 | 1.34 | 1.35+ | .04 |
| Lean belly[d] | 3.99 | 3.51 | 3.71 | 3.22 | .22 |
| Fat belly | 2.91 | 1.77 | 1.95 | 1.77* | .23 |
| Bone belly | 0.54 | 0.57 | 0.53 | 0.51 | .07 |

**Significant line x level of intake interaction ($P < .01$).
*Significant line x level of intake interaction ($P < .05$).
+Significant line x level of intake interaction ($P < .10$).
[a]Right side chilled carcass weight (kg).
[b]RGL = rapid growth line, SGL = slow growth line, AL = ad libitum, LIM = limited to 83 % of predicted ad libitum.
[c]Line means differ ($P < .05$).
[d]Level of intake means differ ($P < .05$).

TABLE XX

LEAST-SQUARES MEANS FOR THE PERCENT COMPOSITION OF THE MAJOR WHOLESALE IN THE FALL REPLICATE[a]

| Line | RGL | | SGL | | |
|---|---|---|---|---|---|
| Level of intake[b] | AL | LIM | AL | LIM | SE |
| Lean ham[cd] | 14.9 | 17.0 | 16.4 | 18.2 | .47 |
| Fat ham | 6.5 | 6.0 | 5.9 | 5.9 | .29 |
| Bone ham[c] | 2.4 | 2.4 | 2.7 | 2.9 | .10 |
| Lean loin | 14.7 | 15.3 | 15.4 | 15.1 | .36 |
| Fat loin[cd] | 10.7 | 8.2 | 8.6 | 6.6 | .49 |
| Bone loin[cd] | 3.5 | 3.8 | 3.7 | 4.1 | .12 |
| Lean shoulder | 15.5 | 17.4 | 18.1 | 18.1+ | .50 |
| Fat shoulder | 8.0 | 6.3 | 6.4 | 6.1+ | .35 |
| Bone shoulder[cd] | 3.5 | 3.8 | 4.1 | 4.5 | .09 |
| Lean belly | 10.9 | 11.9 | 11.3 | 10.8 | .64 |
| Fat belly | 8.0 | 6.0 | 5.9 | 6.0 | .73 |
| Bone belly | 1.5 | 1.9 | 1.6 | 1.7 | .22 |

+Significant line x level of intake interaction ($P < .10$).
[a]Right side chilled carcass weight (kg).
[b]RGL = rapid growth line, SGL = slow growth line, AL = ad libitum, LIM = limited to 83 % of predicted ad libitum.
[c]Line means differ ($P < .05$).
[d]Level of intake means differ ($P < .05$).

level of restriction actually imposed on the two lines. Comparing the two lines fed AL, total fat was significantly higher in the RGL from all four regions. As was true for the spring replicate, no significant line differences were seen when fed LIM. Most of the decrease in percent lean in the RGL-AL was due to decreases in the ham and shoulder, which is in agreement with the spring replicate. However, increased percent fat was due to increases in the loin, shoulder and belly.

Estimates of LTFC and LTGR are presented in tables XXI and XXII for the spring and fall replicates, respectively. Lean gain of RGL-AL pigs was 12.1% greater than SGL-AL, as compared to a 20.8% difference for overall ADG. Comparing the SGL at the two intake levels, the AL pigs gained lean 9.1% faster, as compared to a 8.1% difference in ADG. Limiting intake in the spring reduced lean gain in the RGL, but by a smaller percent than overall ADG was reduced (14.0 vs 6.5%). The line x level of intake interaction (P<.01) for LTFC closely corresponds to the interaction for gross efficiency (Table VII). An improvement in efficiency is seen when the RGL is limit fed, with no change in the SGL. At AL the two lines do not differ in net efficiency of lean growth, while under LIM conditions the RGL is 8.0% more efficient. In the fall, no line differences for LTGR exist at either intake level. Feed restriction significantly (P<.05) reduced lean growth in both lines. As in the spring, LTFC is closely related to gross efficiency (Table X). The SGL pigs are more efficient, with the only significant difference between the RGL-AL and the SGL (P<.05).

A line of pigs selected for improved F/G, ADG and backfat was more efficient than controls in depositing lean on ad libitum (Ellis et al., 1983) or restricted (Henderson et al., 1983) diets. Most of the

TABLE XXI

LEAST-SQUARES MEANS FOR LEAN TISSUE GROWTH RATE AND LEAN TISSUE FEED CONVERSION IN THE SPRING REPLICATE

| Line[a] | RGL | | SGL | | |
|---|---|---|---|---|---|
| Level of intake[a] | AL | LIM | AL | LIM | SE |
| LTGR[bcd] | 0.370 | 0.346 | 0.330 | 0.317 | .007 |
| LTFC[e] | 0.117 | 0.135 | 0.123 | 0.125** | .002 |

**Significant line x level of intake interaction (P < .01).
[a]RGL = rapid growth line, SGL = slow growth line, AL = ad libitum, LIM = limited to 83 % of predicted ad libitum.
[b]Line means differ (P < .05).
[c]Level of intake means differ (P < .05).
[d]Lean tissue gain (kg/d).
[e]Lean tissue gain per unit of feed consumed.

TABLE XXII

LEAST-SQUARES MEANS FOR LEAN TISSUE GROWTH RATE AND LEAN TISSUE FEED CONVERSION IN THE FALL REPLICATE

| Line | RGL | | SGL | | |
|---|---|---|---|---|---|
| Level of intake[a] | AL | LIM | AL | LIM | SE |
| LTGR[cd] | 0.363 | 0.293 | 0.373 | 0.314 | .035 |
| LTFC[be] | 0.101 | 0.116 | 0.122 | 0.124 | .006 |

[a]RGL = rapid growth line, SGL = slow growth line, AL = ad libitum, LIM = limited to 83 % of predicted ad libitum.
[b]Line means differ (P < .05).
[c]Level of intake means differ (P < .05).
[d]Lean tissue gain (kg/d).
[e]Lean tissue gain per unit of feed consumed.

improvement in the index was due to decreased intake, so when differences in intake were removed differences in LTFC were smaller. In a line selected for decreased backfat and increased ADG, select pigs were more efficient depositing lean on either ad libitum or restricted diets, with pigs fed restricted diets being more efficient (McPhee, 1981). Only small differences in LTGR were seen under ad libitum conditions, with select pigs having higher lean gains when restricted. Selection for an index that includes both gain and backfat improves the efficiency of lean growth, while single-trait selection for growth did not improve LTFC under ad libitum intake.

## Conclusions

This study indicates intake is the major correlated response associated with increased growth, while small improvements in efficiency are also seen. Correlated responses may differ for upward and downward selection for growth, but since no control line was included it is not possible to separate these possible differences. It appears the additional intake due to selection for rapid growth is utilized for the deposition of fat and to a lesser extent lean. Seasonal differences in intake suggest the environment under which pigs are selected may affect correlated changes; however, from these data this is inconclusive and further studies are needed.

Alternative methods of selecting for increased growth are of interest, especially lean growth. Improvement in LTFC in an index line was mainly due to a decreased level of intake (Ellis et al., 1983; Henderson et al., 1983). Whittemore (1979) suggested under limited nutrition there is a positive relationship between increased level of intake and increased lean growth and selection under these conditions would put pressure on an increased lean to fat. This should be the case if protein and energy intake is high enough to meet the needs for lean growth. Fowler et al. (1976) pointed out that direct selection for LTFC would avoid problems in construction of indices due to lack of good genetic parameters. Currently in the United States, more emphasis is placed on growth than carcass lean, partially due to lack of price incentives to produce lean. If changes continue that emphasize lean and make it profitable to produce, then alternative method of selection for lean growth will increase in importance.

## Literature Cited


Allen, O. B., J. H. Burton and J. D. Holt. 1983. Analysis of repeated measurements from animal experiments using polynomial regression. J. Anim. Sci. 57:765.

AOAC. 1980. Official Methods of Analysis (13th Ed.). Official Analytical Chemists, Washington DC.

Baird, D. M., A. V. Nalbondov and H. W. Horton. 1952. Some physiological causes of genetically different rates of growth in swine. J. Anim. Sci. 11:292.

Bates, R. O. and D. S. Buchanan. 1988. A comparison of progeny sired by high and low indexing Hampshire and Duroc central test station boars: progeny performance. J. Anim. Sci. 66:1089.

Bichard, M., V. R. Fowler, C. T. Whittemore and A. N. P. Brown. 1979. Objectives: Growth, efficiency, and appetite; test regimes in selection for feed efficiency. European Pig Testing Conference, Harrogate, England.

Brown, M. A. and R. R. Frahm. 1975. Feed efficiency in mice selected for preweaning and postweaning growth. J. Anim. Sci. 41:1002.

Buchanan, D. S. and R. K. Johnson. 1984. Reproductive performance for four breeds of swine: crossbred females and purebred and crossbred boars. J. Anim. Sci. 59:948.

Carr, T. R. 1975. The relationship of K40 net count and probe to body composition changes in growing and finishing swine. Ph.D. Thesis, Oklahoma State University.

Cleveland, E. R., P. J. Cunningham and E. R. Peo. 1982. Selection for lean growth in swine. J. Anim. Sci. 54:719.

Dettmers, A. E., W. E. Rempel and R. E. Comstock. 1965. Selection for small size in swine. J. Anim. Sci. 24:216.

Doornenbal, H. 1972. Growth, development and chemical composition. II. Fatty tissue and chemical fat. Growth 36:185.

Ellis, M., W. C. Smith, R. Henderson, C. T. Whittemore and R. Laird. 1983. Comparative performance and body composition of control and selection line Large White pigs. 2. Feeding to appetite for a fixed time. Anim. Prod. 36:407.

Fine, N. C. and L. M. Winters. 1953. Selection for an increase in growth rate and market score in two inbred lines of swine. J. Anim. Sci. 12:251.

Fowler, V. R., M. Bichard and A. Pease. 1976. Objectives in pig breeding. Anim. Prod. 23:365.

Fredeen, H. T. and H. Mikami. 1986. Mass selection in a pig population: Correlated changes in carcass merit. J. Anim. Sci. 62:1546.

Henderson, R., C. T. Whittemore, M. Ellis, W. C. Smith, R. Laird and P. Phillips. 1983. Comparative performance and body composition of control and selected lines of Large White pigs. 1. On a generous fixed feeding scale for a fixed time. Anim. Prod. 36:399.

Hubbard, D. D. (Ed.). 1981. Guidelines for uniform swine improvement programs. USDA Program Aid.

Jungst, S. B. and D. L. Kuhlers. 1987. Four generations of mass selection for growth to 200 days in Duroc pigs. II. Carcass traits. J. Anim. Sci. 65(Suppl. 1):210 (Abstr.).

Just, A. and O. K. Pedersen. 1976. Danish investigations concerning body composition of pigs in relation to nutrition, sex, and slaughter weight. Livest. Prod. Sci. 3:271.

Kempster, A. J. and D. G. Evans. 1979. The effect of genotype, sex, and feeding regime on pig carcass development. 2. Tissue weight distribution and fat partition between depots. J. Agric. Sci. 93:349.

Kuhlers, D. L. and S. B. Jungst. 1986. Correlated responses in carcass traits to three generations of selection for growth in Landrace pigs. J. Anim. Sci. 63(Suppl. 1) :201 (Abstr.).

Kuhlers, D. L. and S. B. Jungst. 1987. Four generations of mass selection for growth to 200 days of age in Duroc pigs. I. Growth traits. J. Anim. Sci. 65(Suppl. 1):209 (Abstr.).

Malik, R. C. 1984. Genetic and physiological aspects of growth, body composition, and feed efficiency in mice: A review. J. Anim. Sci. 58:577.

McCarthy, J. 1980. Morphological and physiological effects of selection for growth rate in mice. In: A. Robertson (Ed.) Selection experiments in laboratory and domestic animals, July 21-22, 1979. Commonwealth Agricultural Bureaux, pp. 100-109.

McLaren, D. G., D. S. Buchanan and R. K. Johnson. 1987a. Growth performance for four breeds of swine: Crossbred females and purebred and crossbred boars. J. Anim. Sci. 64:99.

McLaren, D. G., D. S. Buchanan and R. K. Johnson. 1987b. Individual heterosis and breed effects for postweaning and carcass traits in four breeds of swine. J. Anim. Sci. 64:83.

McPhee, C. P. 1981. Selection for efficient lean growth in a pig herd. Aust. J. Exp. Agric. Anim. Husb. 32:681.

Metz, S. H. M., P. L. Bergstrom, N. P. Lenis, M. DeWijs and R. A. Dekker. 1980. The effects of daily energy intake on growth rate and composition of weight gain in pigs. Livest. Prod. Sci. 7:79.

NRC. 1979. Nutrient Requirements of Swine (8th Rev. Ed.). National Academy Press, Washington, DC.

Rahnefeld, G. W. 1973. Mass selection for postweaning growth in swine. III. Correlated response in weaning weight and feed efficiency to recurrent selection for post-weaning average daily gain. Can. J. Anim. Sci. 51:497.

Rahnefeld, G. W. and I. Garnett. 1976. Mass selection for post-weaning growth in swine. IV. Selection response and control of population stability. Can. J. Anim. Sci. 56:783.

Richmond, R. J. and R. T. Berg. 1971. Muscle distribution in swine as influenced by liveweight, breed, sex and ration. Can. J. Anim. Sci. 51:41.

Rios, J. G., M. K. Nielsen, G. E. Dickerson and J. A. DeShazer. 1986. Selection for postweaning gain in rats: I. Correlated response in feed utilization and body composition. J. Anim. Sci. 63:34.

Roberts, R. C. 1981. The growth of mice selected for large and small size in relation to food intake and efficiency of conversion. Genet. Res. 38:9.

Roberts, R. C. 1979. Side effects of selection for growth in laboratory animals. Livest. Prod. Sci. 6:93.

Robison O. W. 1976. Growth patterns in swine. J. Anim. Sci. 42:1024.

SAS. 1985. SAS/STAT Guide for Personal Computers (Version 6 Ed.). SAS Inst., Inc, Cary, NC.

Sather, A. P. and H. T. Fredeen. 1978. Effect of selection for lean growth rate upon feed utilization of market hogs. Can. J. Anim. Sci. 58:285.

Stainer, M. W. and L. E. Mount. 1972. Growth rate, food intake and body composition before and after weaning in strains of mice selected for mature body weight. Br. J. Nutr. 28:307.

Timon, V. M. and E. J. Eisen. 1970. Comparison of ad libitum and restricted feeding of mice selected and unselected for postweaning gain. I. Growth, feed consumption and feed efficiency. Genetics 64:41.

Timon, V. M. and E. J. Eisen. 1969. Comparison of growth curves of mice selected and unselected for postweaning gain. Theor. Appl. Genet. 39:345.

Whittemore, C. T. 1979. Nutritional advice to geneticists. European Pig Testing Conference. Harrogate, England.

VITA

Michael David Woltmann

Candidate for the Degree of

Master of Science

Thesis: GROWTH AND CARCASS OF PIGS SELECTED FOR RAPID OR SLOW POSTWEANING GROWTH AND FED AD LIBITUM OR LIMITED RATIONS

Major Field: Animal Science

Biographical:

Personal Data: Born in Atlantic, Iowa, June 8, 1964, the son of David C. and Mary E. Woltmann.

Education: Graduated from Walnut High School, Walnut, Iowa, in May 1982; received Bachelor of Science Degree in Animal Science from Northwest Missouri State University, Maryville, Missouri in May, 1986; completed requirements for the Master of Science degree at Oklahoma State University in December, 1989.

Experience: Raised and worked on a diversified farming operation; graduate research and teaching assistant, Department of Animal Science, Oklahoma State University, 1986 - 1989.

Professional Organizations: American Society of Animal Science, Gamma Sigma Delta.