THE USE OF GROWTH MODELS TO EVALUATE THE CHANGING RESPONSE TO DIGESTIBLE LYSINE IN HIGH-LEAN GROWTH GILTS

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Summary

Conventional response criteria for amino acid research include mean live weight gain and tissue accretion rates over a given weight interval. However, these methods fail to characterize the changing response of tissue accretion to dietary amino acids as body weight increases. For this reason, growth modeling was used to characterize the response to digestible lysine in two experiments (114 gilts each) from 80 to 160 lb and 160 to 300 lb, respectively. Corn-soybean meal diets were formulated to assure that lysine (.54 to 1.04% and .54 to .94% digestible lysine for Exp 1 and 2, respectively) was the first limiting amino acid. Analysis of variance was used to test linear and quadratic responses in cumulative weight gain on test as digestible lysine increased. A time by digestible lysine interaction was detected, indicating that a separate regression equation for each lysine level was necessary. In Exp. 1, ADG and carcass CP accretion were maximized for gilts fed 1.04, .94, and .84% digestible lysine from 80 to 100 lb, 100 to 120 lb, and 120 to 160 lb, respectively. Lipid accretion was minimized for gilts fed .74 to .84% digestible lysine. In Exp. 2, ADG was maximized by feeding .84% from 160 to 205 lb and .74% from 205 to 300 lb. Carcass CP accretion was maximized by feeding .94% digestible lysine, and lipid accretion was minimized for gilts fed .84% digestible lysine from 160 to 300 lb. If feeding graded levels of digestible lysine resulted in parallel lines for carcass protein accretion, mean values would result in accurate data evaluation. However, responses to digestible lysine changed over the feeding period. Therefore, the use of BW and compositional growth curves offers an innovative approach to more accurately characterize the growing pig's response to increased digestible lysine.

(Key Words: Pigs, Gilts, Growth, Carcass Composition, Growth Modeling.)

Introduction

Currently, nutrient requirements for growing-finishing pigs are based on mean growth performance or lean tissue accretion rates over a given time period (ARC, 1981; NRC, 1988). These static estimates of nutrient requirements limit the flexibility to accurately formulate diets for the daily changes in nutrient needs as well as genotype, environment, and health status. Previous research from the University of Illinois indicated that mean ADG and G/F overestimate the methionine requirement for growing finishing pigs compared to mathematical modeling techniques. Therefore, these data suggest a need for improved techniques to determine nutrient requirements. An approach to model body weight gain has been developed at Purdue University to accurately characterize total body weight and tissue weight gain over time. This modeling approach can conceptually improve the estimates for nutrient requirements to maximize carcass protein accretion. The objective of our research was to use these mathematical techniques to characterize the changing response to digest-

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ible lysine in high-lean growth gilts fed from 75 to 160 lb and 160 to 300 lb.

Procedures

Animals and Housing. One-hundred fourteen high-lean growth gilts from a terminal sire line (Pig Improvement Co., L326, Franklin, KY, USA) were used in each of two experiments to determine the digestible lysine requirement to maximize average daily gain (ADG) and carcass protein accretion from 75 to 160 lb (Exp. 1) and from 160 to 300 lb (Exp. 2). The carcass CP and lipid contents for these gilts are given in Table 1. The gilts in Exp. 1 (66 lb body weight) were delivered to the Kansas State University Swine Teaching and Research Center and fed a .90% total lysine diet until they reached a mean weight of 80 lb. In Exp. 2, the gilts were fed a 1.15% total lysine diet from 70 to 160 lb before the experiment was initiated. Three gilts were housed per pen (4 ft × 15 ft pens with solid flooring) in an open-fronted building with six replicate pens per treatment. Each pen contained a single-hole feeder and nipple waterer to provide ad libitum access to feed and water, respectively.

Diet Formulation. Digestible lysine treatments were .54, .64, .74, .84, .94, and 1.04% (.75, .78, .96, 1.03, 1.17, 1.28% total lysine, respectively) for Exp. 1 and .54, .64, .74, .84, and .94% (.73, .87, 1.05, 1.07, and 1.13% total lysine, respectively) for Exp. 2. The corn-soybean meal ratio was adjusted to provide the desired digestible lysine levels. Then, digestible tryptophan, threonine, methionine + cystine, and isoleucine were set using an ideal amino acid ratio. The dietary ME content was increased to 1,550 kcal/lb by adding 3% soybean oil. All other nutrients were formulated in excess of NRC (1988) estimates for the 44- to 110-lb and 110- to 240-lb pig for Exp. 1 and 2, respectively.

Tissue Accretion Rates. Six gilts were selected randomly for slaughter at 80 and 160 lb for Exp. 1 and 2, respectively, and the right side of each eviscerated carcass was ground to determine the percentage moisture, CP, lipid, and ash. When the pen mean weight was approximately 120 and 160 lb (Exp. 1) and 230 and 300 lb (Exp. 2), one pig from each pen (six pigs per treatment) was slaughtered for carcass analyses. The head, leaf fat, and viscera were removed at slaughter and were not included in tissue accretion rate determination. At 24 h postmortem, the right side of each carcass was ground once through a .4-in plate, once through a .25-in plate, and homogenized for 3 min in a ribbon-paddle mixer. Proximate analyses were conducted on each carcass sample. From the chemical analyses, the amounts of CP, lipid, ash, and DM were determined for each carcass based upon cold carcass weight. Moisture content was determined by subtracting the percentage of DM from 100%. Thus, initial composition, determined from chemical composition of carcass weight, was subtracted from chemical composition determined at 120 and 160 lb (Exp. 1) and 230 and 300 lb (Exp. 2). Tissue accretion rates were determined from the difference between final and initial composition, divided by the days on test. These means then were used to test linear and quadratic effects of digestible lysine.

Weight Interval Performance Analyses. Analysis of variance with the GLM function of SAS was used to obtain the least square means for ADG and carcass CP and lipid accretion from 80 to 160 lb and 160 to 300 lb. Linear and quadratic polynomials were used to evaluate the effect of digestible lysine. Break-point analysis was used to determine the inflection point at 95% of maximal response when the quadratic function was significant. The inflection point for a lysine requirement was determined for ADG and carcass protein and lipid gain, from 80 to 160 lb. From 160 to 300 lb, the inflection point was not estimated for ADG and carcass protein and lipid gain, because no significant quadratic response was observed.

Regression Analyses. Two functions, one relating live weight to time and a second relating the body component mass to live weight, were used to establish the body component accretion rates at each age or weight. Regression analysis was used first to

determine the relationship between live weight gain and days on test by using the following equation to solve for regression coefficients:

$$\text{Cumulative live weight gain on test} = b_0 + b_1(\text{day}) + b_2(\text{day}^2).$$

An allometric equation then was used to determine the coefficients of carcass CP and lipid accretion relative to live weight:

$$Y = aX^b$$

where Y = carcass CP or lipid, a = scale constant, X = body weight, and b = relative growth coefficient. The equation was linearized as log Y = log a + b log X to utilize least squares regression analyses. Component (carcass CP or lipid) gain then was related to live weight gain by multiplying the derivative of live weight over time by the derivative of component weight over live weight.

Results

The initial body weight (b_o) for the relationships between the change in live weight gain over time were similar for all digestible lysine levels at 80 lb (Exp 1.) and 160 lb (Exp 2.; Table 1). The linear (b_1) and quadratic (b_2) terms were different ($P<.001$) for each digestible lysine level in both Exp. 1 and 2. The b_1 term increased as digestible lysine level increased from .54 to 1.04% , resulting in greater ADG for gilts fed increased digestible lysine (Figure 1.). The b_2 values were positive for gilts fed .54, .74, and .84%, indicating increased ADG as body weight or time increased. The negative b_2 terms for gilts fed .64, .94, and 1.04% suggest reduced ADG as body weight increased. For Exp 2, the b_1 and b_2 terms were different ($P<.001$) for each digestible lysine level. The b_1 term increased as digestible lysine increased from .54 to .94%, resulting in greater ADG ($P<.001$). Average daily gain (Figure 2) was reduced as body weight increased, as reflected by the negative b_2 terms for each digestible lysine level. These b_2 terms were influenced ($P<.001$) by digestible lysine for gilts fed .64, .84, and .94% digestible lysine.

The intercepts (a) developed for the carcass CP allometric functions from 80 to 160 lb decreased ($P<.001$) as digestible lysine increased (Table 2). Growth coefficients (b) were greater ($P<.001$) as digestible lysine increased from .54 to 1.04%, peaking at .74%. The intercept for carcass lipid accretion was influenced ($P<.001$) by digestible lysine. Carcass lipid growth functions (b) were reduced ($P<.001$) as a result of increased digestible lysine. Similarly, carcass CP and lipid intercepts were influenced ($P<.001$) as digestible lysine increased in Exp. 2 (Table 6). The growth coefficients for carcass CP increased ($P<.001$), whereas carcass lipid coefficients decreased ($P<.001$).

The data in Fig. 1 represent weight interval performance analyses and the corresponding regression analyses for ADG and carcass CP and lipid accretion from 80 to 160 lb. Weight interval performance analyses for ADG (Panel A) indicated greater (linear, $P<.01$) gains as a result of increased digestible lysine. Average daily gain appears to be maximized for high-lean growth gilts fed .84 to .94% (18 g/d digestible lysine or 22 g/d total lysine intake) digestible lysine. Live weight growth curve analyses of ADG (Panel B) indicated maximum ADG ($P<.001$) for high-lean growth gilts fed 1.04, .94, and .84% digestible lysine from 75 to 100 lb, 100 to 120 lb, and 120 to 160 lb, respectively. These diets would provide 16, 18, and 18 g/d digestible lysine intake (19, 21, and 21 g/d total lysine intake, respectively) for the specified weight periods. Weight interval performance analyses indicated increased (quadratic, $P<.05$) CP accretion as digestible lysine increased (Panel C). The inflection point for 95% of the maximum response was .79 g/kg (14 g/d) digestible lysine (9.4 g/kg or 17 g/d total lysine). Regression analyses (Panel D) showed that carcass CP accretion was maximum ($P<.001$) for gilts fed 1.04, .94, and .84% digestible lysine from 75 to 100 lb, 100 to 120 lb, and 120 to 160 lb. The analysis of CP accretion would result in identical lysine

estimates (digestible and total) as did the ADG analysis. Carcass lipid accretion decreased (quadratic, $P<.10$) as digestible lysine increased (Panel E). The inflection point for minimum carcass lipid gain was calculated at .71% (13 g/d) digestible lysine (.84% or 15 g/d total lysine). The regression of carcass lipid accretion over body weight indicated a linear increase ($P<.001$) in lipid gain for all dietary treatments, except gilts fed 10.4 g/kg (Panel F).

Weight interval performance analyses from 160 to 300 lb indicated that digestible lysine did not influence ($P>.10$) ADG (Figure 2.; Panel A). Numerically, ADG apparently is maximized for gilts fed .74% (22 g/d) digestible lysine or .88% (27 g/d) total lysine. Regression analyses of body weight gain over time (Panel B) indicated maximum ($P<.001$) ADG for gilts fed .84 and .74% digestible lysine from 160 to 205 lb and 205 to 300 lb, respectively. These estimates would provide 25 and 22 g/d digestible lysine intake (30 and 26 g/d total lysine intake). Carcass CP accretion (Panel C) was greater (linear, $P<.10$) as digestible lysine increased. This increase in CP accretion would require .94% (28 g/d) digestible lysine or 1.12% (33 g/d) total lysine. Regression analyses of carcass CP accretion over body weight (Panel D) was maximum ($P<.001$) for gilts fed .94% (28 g/d) digestible lysine or 1.12% (33 g/d) total lysine. However, as body weight increased, carcass CP accretion continually decreased ($P<.001$). Carcass lipid accretion (Panel E) was not influenced ($P>.10$) by digestible lysine in high-lean growth gilts fed from 160 to 300 lb. The regression analyses of carcass lipid accretion (Panel F) indicated increased lipid accretion for gilt fed all diets, except .84% digestible lysine.

Discussion

These results indicate that the response to digestible lysine changes as body weight increased from 80 to 300 lb. Traditionally, nutrient requirement estimates are established by using mean performance over a given weight period. These estimates are determined for mean performance from 110 to 280 lb in the National Research Council's (1988) amino acid requirements for finishing pigs. Use of these techniques obviously limits practical diet formulation because of differences in the pigs' genetic potential, health status, environmental conditions, and gender, which will change the shape of the growth curves.

The data from Figure 1 suggest that ADG and carcass protein were limited by lysine intake. Thus, as digestible lysine was increased from .54 to .94%, the rates of total live weight gain and carcass protein gain increased dramatically. Gilts fed deficient levels of dietary lysine (.54%) attained only 67% of their genetic potential for carcass protein gain from 80 to 160 lb. The differences in the regression lines represent the influence of digestible lysine on the body weight where peak carcass protein gain was attained. These differences could be explained by previous nutrient intake that may influence the shape of the compositional curves, offering the potential for compensatory gain. Our data suggest that the .74% digestible lysine diet fed prior to the first experiment limited carcass protein gain. Thus, feeding greater levels of digestible lysine resulted in large increases in carcass protein gain, potentially as compensatory gain, as well as meeting the lysine need for maximum carcass protein gain. Secondly, the resulting decrease in carcass protein gain for gilts fed 1.04% digestible lysine may be related to decreased net energy for gain because of increased excess amino acid degradation. Lipid accretion increased as body weight increased from .54 to 1.04% digestible lysine. However, it increased to a lesser extant for gilts fed .84 to .94% digestible lysine compared to those fed .54 to .64% digestible lysine. Carcass lipid gain is limited when adequate digestible lysine is fed.

During the finishing period (160 to 300 lb), ADG and carcass protein gain decreased as body weight increased (Figure 2). This reduction suggests that carcass protein gain was beyond the inflection point for maximum gain. These responses are similar to those from Purdue University indicating that car-

cass protein gain per day decreased as body weight increased from 130 to 280 lb. The magnitude of response to digestible lysine was not as great as the responses from 80 to 160 lb. The total lysine intake in the finisher gilts is 5 g/d greater to support carcass protein gains that are 20 to 30 g/d less than those of grower gilts. This is apparent in reduced feed efficiencies as body weight increases. The poorer efficiencies for lysine use also can be attributed to increased lipid deposition that resulted from greater feed intake and excess nutrient intake.

Thus, performance and carcass composition are poorer as a result of increased body weight. Our data suggest increased carcass protein gain and decreased lipid gain as a result of greater digestible lysine intake. However, the efficiency of lysine utilization is reduced for gilts fed from 80 to 160 lb. This reduction is evident by the decreased slope of carcass protein gain on lysine intake. However, the increased carcass protein gain was proportionally greater for nonlean tissue gain (i.e., lipid gain), which is evident in our data. Although carcass protein gain is greater with increased digestible lysine, the cost of achieving maximum carcass protein gain is not economically feasible. It becomes a question of economics to determine the level of lysine that can be fed for maximum profit.

In conclusion, the growth and composition models described in this experiment indicate the importance of regression models to accurately describe nutrient requirements in growing-finishing pigs. In the growing period (80 to 160 lb), the models more accurately estimated digestible lysine for maximum carcass protein gain as body weight increased. Although digestible lysine gave less of a response in the finishing period (160 to 300 lb), the models characterized the diminishing response to digestible lysine as body weight increased. Thus, maximal profit will dictate the level of digestible lysine that can be fed in the finishing period rather than maximal carcass protein gain.

Table 1. Live Weight Growth Parameters for High-Lean Growth Gilts Fed from 80 to 160 lb and 160 to 300 lb where Live Weight Gain on Test = $b_o + b_1(days) + b_2(days)^2$[a]

	80 to 160 lb			160 to 300 lb		
Digestible lysine, %	b_o	b_1	b_2	b_o	b_1	b_2
.54	75.610	1.306 (.082)***[a]	.002 (.002)***	162.439	1.984 (.070)***	-.002 (.001)
.64	74.440	1.637 (.088)***	-.003 (.002)***	159.940	2.110 (.070)***	-.004 (.001)**
.74	75.610	1.393 (.088)***	.003 (.002)***	158.331	2.061 (.071)***	-.002 (.001)
.84	75.668	1.566 (.102)***	.005 (.003)***	157.390	2.190 (.069)***	-.005 (.001)***
.94	74.557	1.875 (.103)***	-.002 (.003)***	159.001	2.123 (.068)***	-.004 (.001)***
1.04	75.610	2.194 (.094)***	-.014 (.002)***	--	--	--

[a]Where liveweight gain on test = $b_o + b_1(days) + b_2(days)^2$
[b]Probability levels of deviations of coefficients from 1.00, ** P<.01, *** P<.0001.

Table 2. Growth of Carcass CP and Lipid Components using the Relationship of $Y = aX^b$, where Y Is the Component and X Is the Live Weight (lb), for High-Lean Growth Gilts fed from 80 to 160 lb

	Carcass lean gain			Carcass lipid		
Digestible lysine, %	a	b	R^2	a	b	R^2
.54	.2064***[a]	2.314 (.086)***	.98	.0108***	1.742 (.178)***	.87
.64	.1804***	2.396 (.090)***	.98	.0229***	1.526 (.156)***	.87
.74	.1188***	2.660 (.130)***	.96	.0401***	1.364 (.129)***	.87
.84	.1320***	2.592 (.092)***	.98	.0630***	1.240 (.154)***	.79
.94	.1342***	2.589 (.101)***	.97	.0591***	1.263 (.138)***	.83
1.04	.1415***	2.545 (.123)***	.96	.00606**	1.240 (.140)***	.82

[a]Probability levels of deviations of coefficients from 1.00, *** P<.0001.

Table 3. Growth of Carcass CP and Lipid Components using the Relationship of $Y = aX^b$, where Y Is the Component and X Is the Live Weight (lb), for High-Lean Growth Gilts fed from 160 to 300 lb

	Carcass lean gain			Carcass lipid gain		
Digestible lysine, %	a	b	R^2	a	b	R^2
.54	.9702***[a]	1.580 (.128)***	.91	.0046***	1.876 (.178)***	.87
.64	.7080***	1.734 (.141)***	.90	.0022***	2.030 (.152)***	.91
.74	.7896***	1.679 (.103)***	.94	.0053***	1.843 (.198)***	.85
.84	.6222***	1.797 (.200)***	.85	.0134***	1.622 (.179)***	.84
.94	.5232***	1.885 (.110)***	.95	.0059***	1.836 (.179)***	.87

[a]Probability levels of deviations of coefficients from 1.00, *** $P < .0001$.

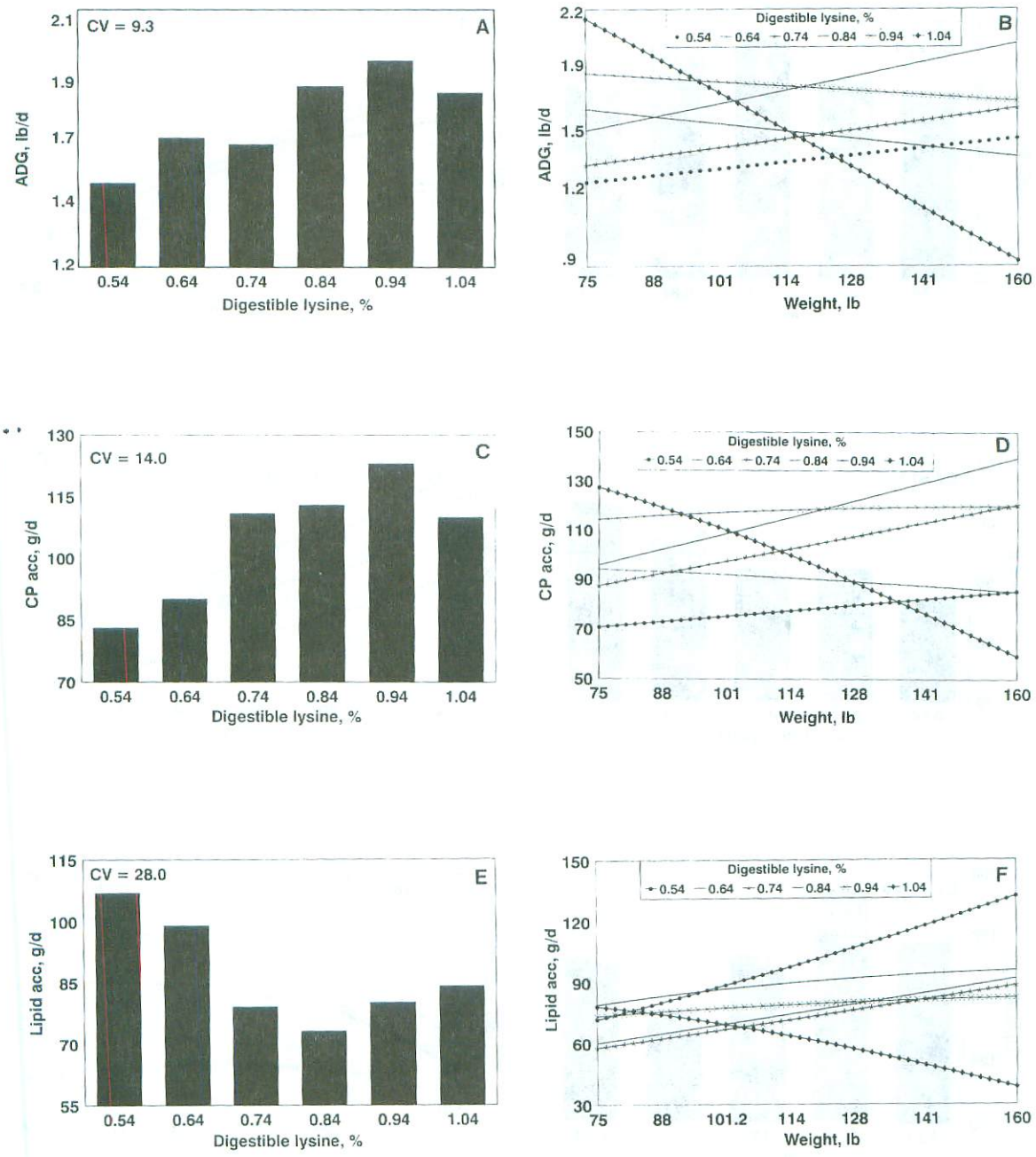

Figure 1. **The Influence of Digestible Lysine (.54 to 1.04%) in High-Lean Growth Gilts Fed from 80 to 160 lb on End-Point ADG (Panel A), the Change in Live Weight Gain over Time (Panel B), End-Point Lean Gain (Panel C), the Change in Lean Gain over Time (Panel D), End-Point Carcass Lipid Accretion (Panel E), and the Change in Carcass Lipid Accretion over Time (Panel F)**

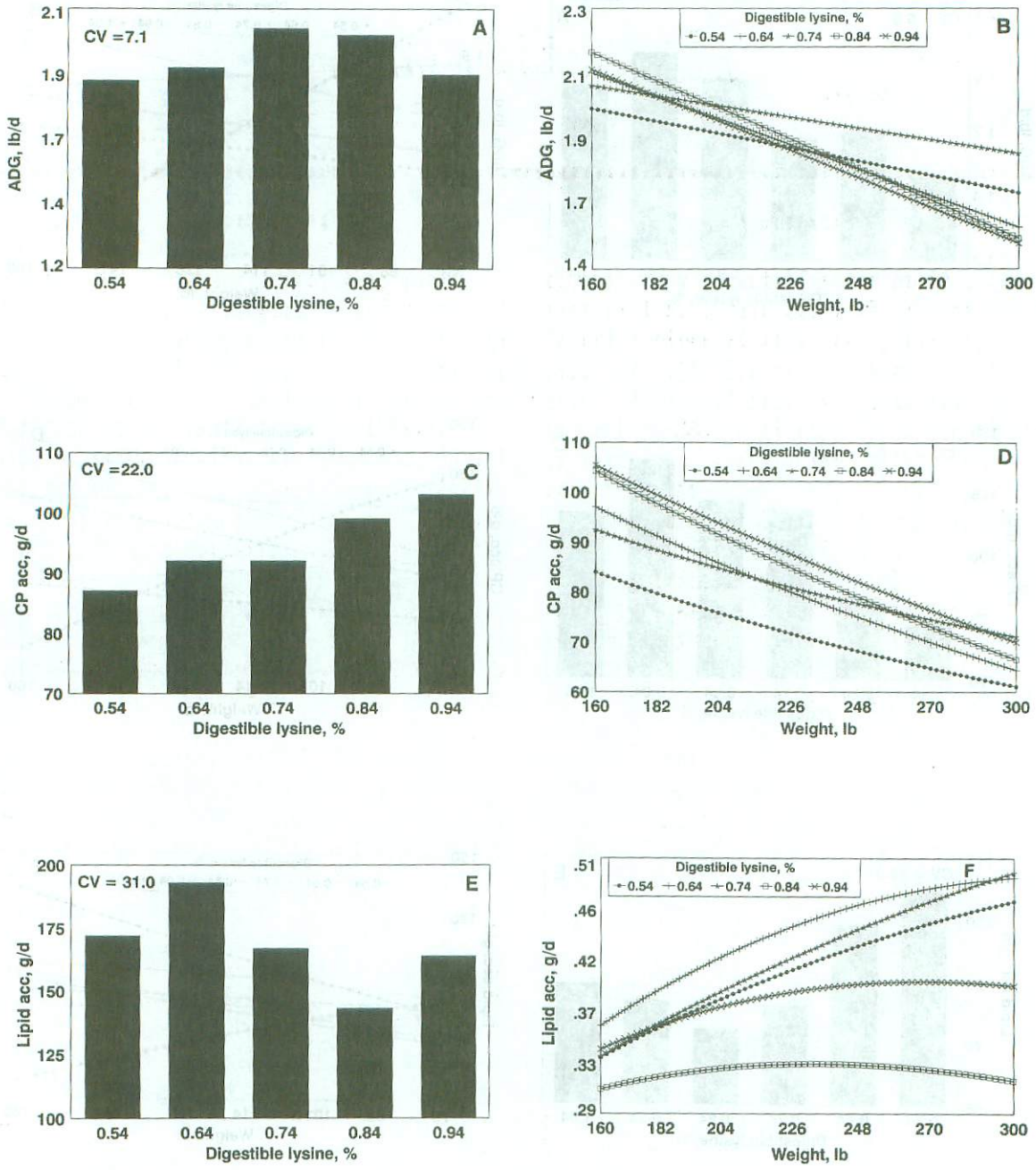

Figure 2. **The Influence of Digestible Lysine (.54 to .94%) in High-Lean Growth Gilts Fed from 160 to 300 lb on End-Point ADG (Panel A), the Change in Live Weight Gain over Time (Panel B), End-Point Lean Gain (Panel C), the Change in Lean Gain over Time (Panel D), End-Point Carcass Lipid Accretion (Panel E), and the Change in Carcass Lipid Accretion over Time (Panel F)**