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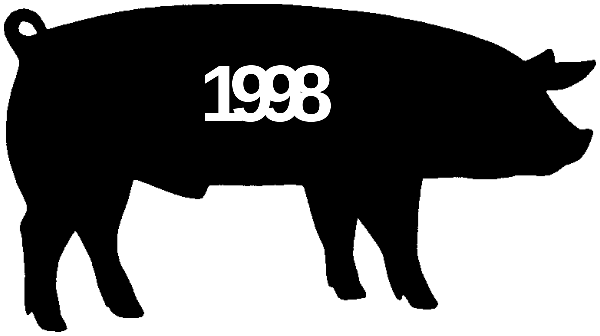
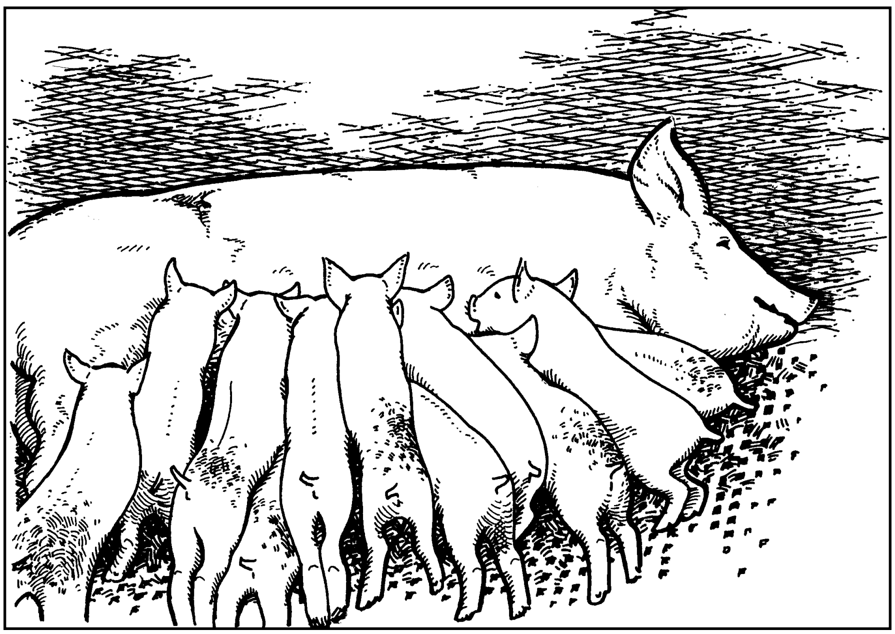


NEBRASKA SWINE REPORT



- Reproduction
- Genetics
- Health
- Nutrition
- Economics
- Housing

Prepared by the staff in Animal Science and cooperating Departments for use in Extension, Teaching and Research programs.

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The 1998 Nebraska Swine Report was compiled by Duane E. Reese, Associate Professor and Extension Swine Specialist, Animal Science, Department of Animal Science.

Cover Art Caption:
Litter size is an important aspect of pork production. Research results from studies where litter size was a response variable are featured in this report.

1998
Nebraska Swine Report

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Efficacy of Once (1x) Versus Twice (2x) Daily Physical or Fence-line Contact with Boars for Stimulating Earlier Puberty in Gilts

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Tom McGargill
Norm Rohda[1]

Summary and Implications

The effectiveness of twice daily (2x) versus once daily (1x) boar exposure (BE) and the possible interaction of frequency of BE and type of BE (physical, PBE, versus fence-line, FBE) for stimulating earlier puberty in gilts was evaluated. Gilts (n=120) from the R-LS line of the gene pool herd at the University of Nebraska-Lincoln were, within litter, assigned randomly to two frequencies of BE (1x versus 2x per day) and two types of BE (PBE versus FBE) plus one additional treatment where gilts were maintained in continuous fence-line contact with boars (CFBE). Treatments were initiated when gilts in each replicate reached 160 days of age. Duration of BE for 1x and 2x BE was 10 minutes per exposure. Two sets of three White Line boars (10 months of age at start) were used to stimulate the gilts. Gilts were maintained in groups of eight per pen and were taken to the boar room for stimulation. Physical boar exposure induced a more rapid and more synchronous first estrous response than FBE. The average interval to first estrus after initial BE was shorter (20.2 versus 29.7 days, P<.01) and age at puberty occurred 8.8 days earlier (P<.02) in PBE than FBE gilts. Interval to first estrus tended to be shorter in gilts receiving 2x versus 1x contact with boars (21.5 versus 28.4 days, P<.08). Puberty also tended to occur earlier in gilts receiving 2x versus 1x BE (182.8 versus 191.1 days, P<.06). Interval to estrus and age at puberty in gilts subjected to CFBE did not differ from the other FBE treatments but were increased compared to gilts receiving PBE. Physical BE is required to achieve maximal pubertal response to boar exposure. Added frequency of BE (2x versus 1x per day) tended to decrease pubertal age overall, but it appears the greatest effect of increasing the frequency of boar exposure occurs when gilts are being stimulated with FBE.

Introduction

Evaluation of the influence of frequency of contact with boars on the efficacy of boar exposure (BE) for stimulating earlier puberty in gilts has demonstrated BE frequencies of less than once daily decreased the effect. In Nebraska studies, providing boar contact on alternate days produced comparable pubertal responses to once daily BE when applied to gilts starting at 130 days of age, but was less effective than once daily BE when imposed at 160 days of age. Australian researchers have reported the effect of boars on puberty attainment was reduced when applied at less-than-once-daily frequencies. More recently, Australian researchers reported two or three contacts per day, induced earlier puberty than once daily contact. In gilts responding before termination of their experiment (70% pubertal/group), puberty was achieved 5.7 days and 12.8 days earlier in gilts provided twice per day and three times per day physical contact with boars compared to gilts receiving once daily BE (196 day average). The objectives of the present experiment were to: (1) evaluate the effectiveness of twice-daily versus once-daily boar exposure for stimulating earlier puberty in gilts, and (2) determine whether the pubertal response to frequency of BE differs with type of BE provided (fence-line, FBE, versus physical boar exposure, PBE).

Materials and Methods

One-hundred twenty gilts from the R-LS line of the gene pool herd at UNL were assigned randomly within litter to a replicated (3 pens per treatment of 8 gilts per pen) factorial experiment involving two frequencies of BE (once, 1x, versus twice, 2x, daily) and two types of BE (FBE versus PBE). An additional group was maintained in continuous fence-line contact with boars (CFBE). Treatments were initiated when gilts in each replicate reached 160 days of age. Gilts were bled for progesterone determinations 7-10 days before and at the start of treatment to determine ovarian status. Gilts with elevated progesterone were deleted from the study. Duration of BE for once daily and twice daily BE was 10 minutes per exposure.

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Boar exposure and heat detection (10 minutes duration) were accomplished by moving gilts from their home room (rooms housing gilts on once and twice daily BE treatments) into contact with boars housed in the CFBE room. Gilts assigned to the CFBE room were relocated to another room before each session of once daily or twice daily BE. Two sets of three White Line (WL) boars (10 mo) were maintained in fence-line contact with pens of CFBE gilts. FBE gilts were placed in a pen adjacent to a pen of boars and received contact with boars for 10 minutes through a 16 foot pen divider equipped with vertical open bars (4 inch spacings). Boars from each set were distributed individually to pens on alternate days before PBE gilts were brought to the CFBE room. Each pen of PBE gilts was placed in a pen with a single boar for 10 minutes. Gilts were observed closely for symptoms of estrus during the first 5 minutes and estrous gilts were removed from the pen as soon as observed to prevent unwanted matings and keep boars actively working other gilts in the pen. Each set of boars was rotated daily between the two boar pens to insure that all gilts received exposure to different boars on alternate days. CFBE gilts were returned to their home pens and heat checked once daily for a 10 minute period. This typically occurred after a 90 minute to 2 hour period away from boars.

Results and Discussion

Physical boar exposure, especially twice daily exposure, induced a more rapid and synchronous first estrous response than FBE. Fifty-four percent of PBE$_{2x}$ gilts expressed pubertal estrus during the first 10 days of BE. This compared to 27.3 percent, 21.7 percent, 17.4 percent and 13.6 percent for the PBE$_{1x}$, FBE$_{2x}$, CFBE and FBE$_{1x}$ groups, respectively (Figure 1). PBE$_{1x}$ gilts showed the greatest first estrous response during the second 10-day period (45.4%) and had achieved a comparable estrous response to PBE$_{2x}$ gilts by 20 days after initiation of BE.

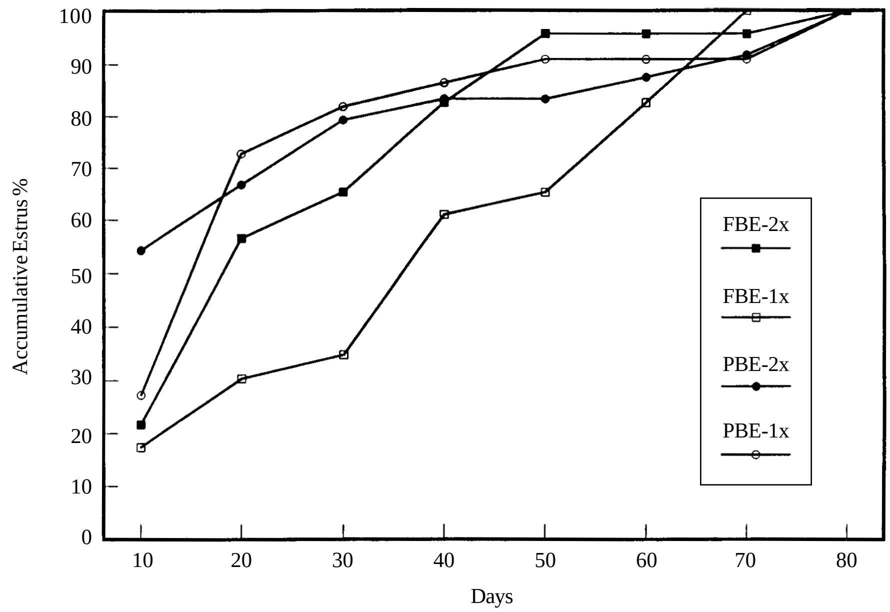

Figure 1. Accumulative estrous response (%) by 10-day intervals from initial boar exposure at 160 days. FBE - 2 x = fence-line boar exposure twice per day; FBE - 1x = fence-line boar exposure once per day; PBE - 2x = physical boar exposure twice per day; PBE -1x = physical boar exposure once per day.

PBE gilts maintained a substantial advantage in first estrous percentage over FBE gilts during the first 30 days of BE. After 30 days of BE, FBE$_{2x}$ gilts achieved a cycling rate comparable to PBE gilts and maintained an advantage over FBE$_{1x}$ gilts through 50 days of BE (Figure 1). After initial BE, the average interval to first estrus was shorter for PBE gilts than FBE gilts (20.2 versus 29.7 days, P<.02) and tended to be shorter for gilts exposed to boars twice daily versus once daily (21.5 versus 28.4 days, P<.08, Table 1). FBE$_{2x}$ gilts expressed first estrus faster on average than FBE$_{1x}$ gilts (23.4 versus 36.0 days, P<.01). CFBE gilts responded similarly to FBE$_{1x}$ gilts (average interval, 31.9 days).

Both type and frequency of BE affected mean age at puberty (Table 2). PBE gilts reached puberty 8.8 days earlier (P<.02) than FBE gilts and gilts provided twice daily BE expressed first estrus 8.3 days earlier (P<.06) than gilts provided once daily BE. Average pubertal age in CFBE gilts (192.8 days) was comparable to that produced with once daily FBE (197.9 days). Although no statistically significant interactions between type and frequency of BE were detected for any of the responses measured, they suggest that further evaluation of interaction effects is warranted. While the pubertal response to FBE*2x* was neither as rapid nor synchronous as responses to PBE, the treatment achieved

Table 1. Interval to estrus (average ± SE, days) after initiation of boar exposure (BE)

Type of BE[a]	Frequency of BE 1x/d	2x/d	Combined
FBE	36.0 ± 3.9	23.4 ± 3.9	29.7
PBE	20.9 ± 4.0	19.6 ± 3.8	20.2[b]
Combined	28.4	21.5[c]	

[a]FBE and PBE = Fence-line and physical boar exposure, respectively.
[b]FBE versus PBE, P<.02.
[c]1x versus 2x per d, P<.08.

Table 2. Age at puberty (average ± SE, days) as affected by type and frequency of boar exposure (BE)

Type of BE[a]	Frequency of BE 1x/d	2x/d	Combined
FBE	197.9 ± 4.0	184.9 ± 4.0	191.4
PBE	184.3 ± 4.0	180.8 ± 3.9	182.6[b]
Combined	191.1	182.8[c]	

[a]FBE and PBE = Fence-line and physical boar exposure, respectively.
[b]FBE versus PBE, P<.02.
[c]1x versus 2x per d, P<.06.

a similar interval to first estrus and similar age at puberty as expressed by PBE gilts. In contrast, under the conditions of this experiment, FBE_{1x} and CFBE were clearly less effective in inducing a rapid and synchronous first estrous response in gilts.

Physical BE, as previously demonstrated in Nebraska studies and elsewhere, was clearly more efficacious than FBE for stimulating earlier puberty in gilts. Frequency of BE had a less consistent effect but twice daily BE tended to be more effective than once daily BE. Although the interactions between type and frequency of BE were not significant, the data suggests frequency of BE may be less of a concern with PBE than with FBE. The poor pubertal response achieved with CFBE was surprising and may suggest the mechanism triggering pubertal estrus in response to BE is more sensitive to shorter and more frequent boar stimuli when applied on the fence-line. This seems to be the situation regarding estrus expression by mature cycling gilts, which show a higher and more rapid estrous response when housed away from boars and provided a new or novel boar stimulus to detect estrus. Future research will be conducted to confirm and expand these findings and determine whether age or stage of gilt maturation influences the response to type and frequency of boar exposure and their possible interaction.

Conclusion

Physical BE is required to achieve the maximal pubertal response to boar exposure. It is suggested, but not proven, that increasing the frequency of BE from once to twice per day offers little advantage when using PBE but may be important when using FBE. Questions remain regarding the relative ineffectiveness of CFBE in this experiment. It is important to confirm and expand these findings in the future.

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[1]Dwane R. Zimmerman is a Professor, Tom McGargill and Norm Rohda are research technicians in the Animal Science Department.

Follicular Development in Gilts Selected for High Ovulation Rate and Embryo Survival Versus Randomly Selected Control Line Gilts

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Dwane R. Zimmerman[1]

Summary and Implication

The patterns of follicular development during the proestrous period were compared in gilts selected for an index of high ovulation rate and high prenatal survival (White Line-2, WL-2) and randomly selected controls (White Line-1, WL-1) on days 0, 2, 3, 4, 5 and estrus after induced luteolysis with $PGF2\alpha$ on day 13 (day 0) of the estrous cycle. Numbers of follicles (F) equal or greater than 2 mm in diameter were categorized and recorded as follows: small (SF, 2 to 2.9 mm), medium-1 (M1F, 3 to 4.9 mm), medium-2 (M2F, 5 to 6.9 mm) and large (LF, equal or above 7 mm). The population of SF was greater in WL-1, whereas the population of M1F was greater in WL-2 gilts during the early follicular phase. The SF and M1F populations declined rapidly in both lines between days 0 and 4. White Line-2 gilts maintained a larger pool of M2F between days 0 and 4. Medium-2 follicles declined in both lines between days 4 and 5, but the loss of M2F was much greater in WL-2 gilts. Large follicles developed earlier and accounted for a greater percentage of the follicles in WL-1 gilts to day 4. The reverse was true on day 5 and at estrus. White Line-2 gilts tended to have greater numbers of large follicles than WL-1 gilts at estrus. White Line-2 gilts maintain a larger pool of M2F during most of the follicular phase and must select a greater number of these follicles during the late follicular phase to achieve their ovulation rate advantage. It is possible the M2F population is healthier in WL-2 gilts.

Introduction

Variation in litter size is determined by the number of follicles that ovulate and release viable ova, the percentage of ova fertilized by sperm and the percentage of beginning embryos and fetuses that survive in utero during gestation and are born alive.

Selection for high ovulation rate alone (Relax Select, RS line) in the University of Nebraska gene pool population increased ovulation rate

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by about 3.2 ova over randomly selected control (C) line gilts but increased pigs born alive less than one pig per litter after nine generations of selection. The limited litter size response led to the design of a second selection experiment where selection was based on an index of the ability of females to maintain large litters to day 50 of gestation (percent prenatal survival) and ovulation rate (see Johnson, Nebraska Swine Report 1990). This experiment utilized a Large White x Landrace composite population and has proved more effective at increasing both ovulation rate and litter size. The mean ovulation rate for the select line (17.04) was about three ova higher than the mean for the control line (14.07) after five generations.

The objective of this study was to determine what changes in follicular development allow select line gilts to achieve substantially greater ovulation rate. The pattern of follicular development during the follicular phase of the estrous cycle was compared in gilts selected for an index of ovulation rate and prenatal survival (White Line-2, WL-2) and randomly selected control gilts (White Line-1, WL-1).

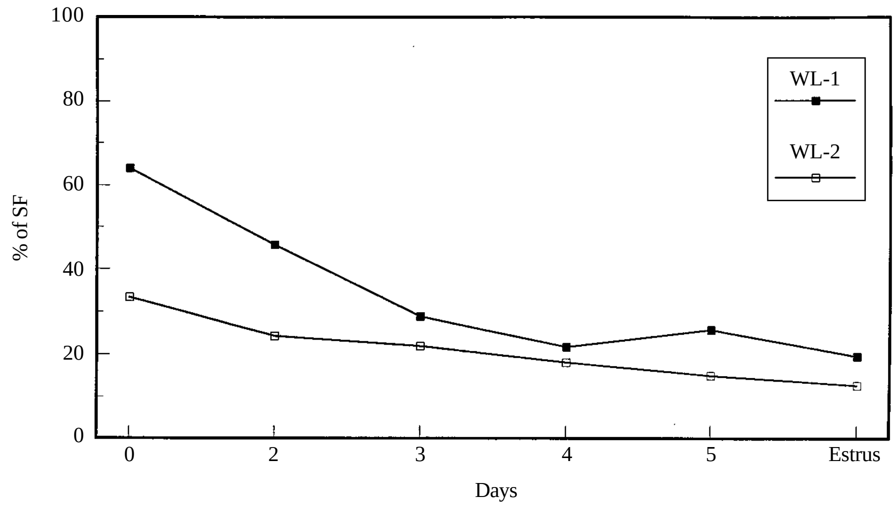

Figure 1. Line difference in relative percentage of small follicles (SF) following PGF2-alpha on d 13.

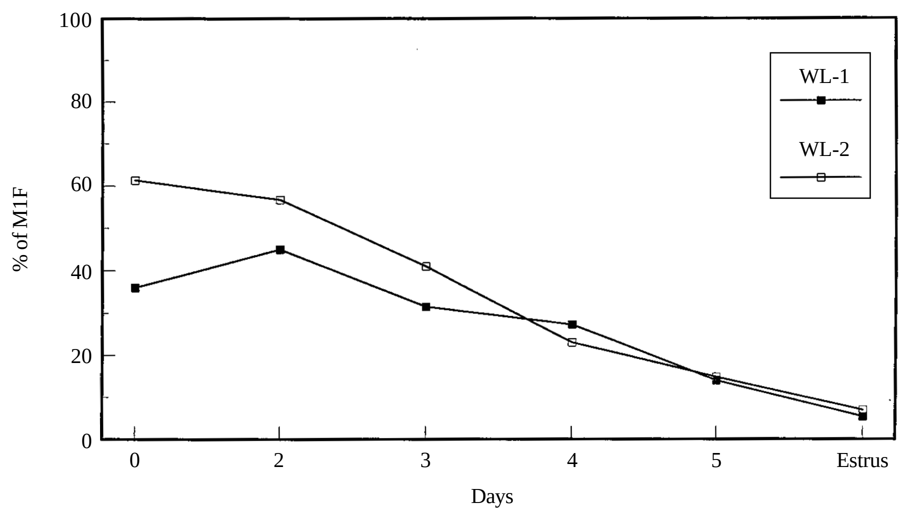

Figure 2. Line difference in relative percentage of medium 1(M1F) follicles following PGF2-alpha on d 13.

Materials and Methods

Seventy-two tenth generation WL-1 and WL-2 gilts were used to compare the pattern of follicular development. Gilts were assigned randomly within sire for ovary recovery on days 0, 2, 3, 4, 5 and estrus after induced luteolysis (regression of corpora lutea) with PGF2α (10 mg Lutalyse) on day 13 (d 0) of the estrous cycle. Gilts from WL-1 and WL-2 represented the progeny of 11 and nine sires, respectively. These gilts were eight to 11 months of age and weighed between 209 and 330 pounds when evaluated. They had experienced two or more estrous cycles before assignment to experiment. Distribution of gilts by line and day (d) of evaluation were: d 0 (n = 7 WL-1 and 5 WL-2), d 2 (n = 7 WL-1 and 6 WL-2), d 3 (n = 5 WL-1 and 6 WL-2), d 4 (n = 5 WL-1 and 6 WL-2), d 5 (n = 7 WL-1 and 6 WL-2) and estrus (n = 5 WL-1 and 7 WL-2).

Ovaries were recovered at slaughter and placed in .9 percent saline on ice. The numbers of corpora ablicantia (CA) were recorded as a measure of ovulation rate at the previous estrus. Numbers of follicles (F) equal or greater than 2 mm in diameter were categorized and recorded as follows: small (SF, 2 to 2.9 mm), medium-1 (M1F, 3 to 4.9 mm), medium-2 (M2F, 5 to 6.9 mm) and large (LF, equal or greater than 7 mm). Follicle numbers for different size categories were not normally distributed, so the data concerning follicle numbers were converted to relative percentage for each gilt (dividing number of follicles in a given size category by the total number of follicles in all four size categories) before the data were analyzed statistically.

Results and Discussion

Overall, WL-2 gilts ovulated 6.6 more follicles than WL-1 gilts at the pretreatment estrus (20.4 versus 13.8, $p<.01$). This difference is similar to those reported in earlier summaries.

During the early follicular phase, the population of SF was greater in WL-1 gilts whereas the population of M1F was greater in WL-2 gilts (Table

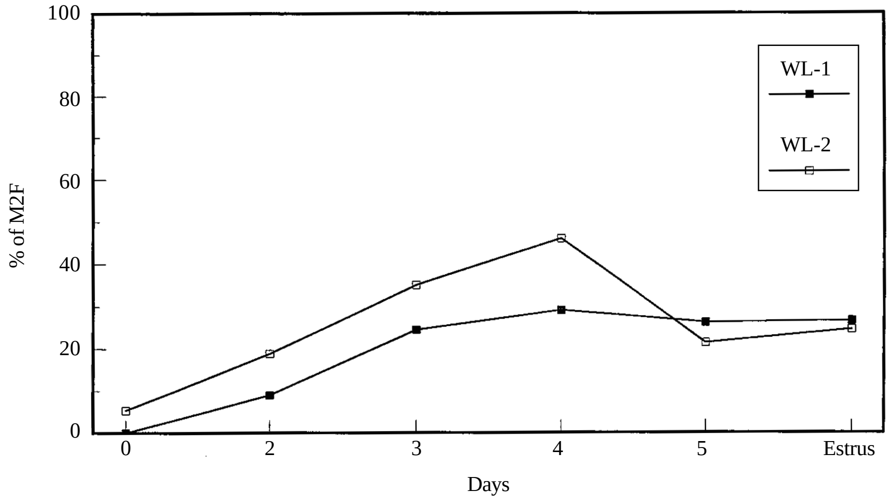

Figure 3. Line difference in relative percentage of medium 2 (M2F) follicles following PGF2-alpha on d 13.

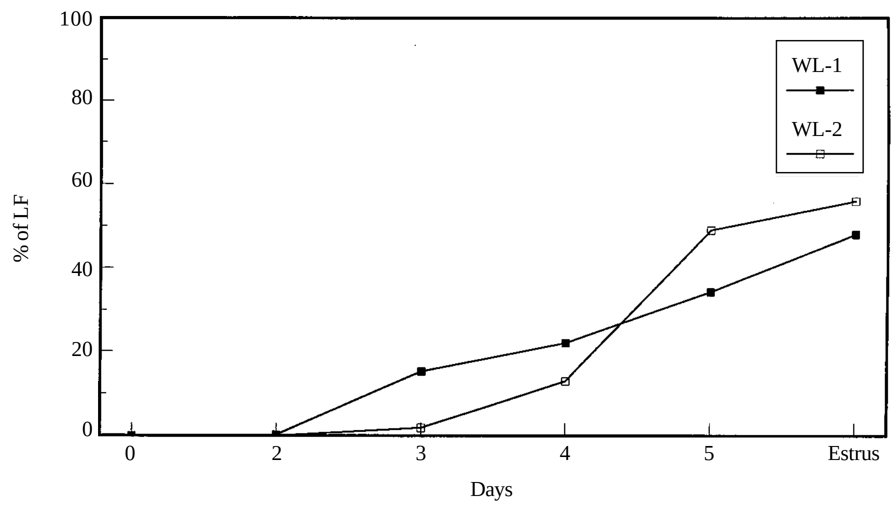

Figure 4. Line difference in relative percentage of large follicles (LF) following PGF2-alpha on d 13.

1). The relative percentages of SF and M1F declined over time in both lines (Figure 1 and Figure 2). However, the decline of SF between days 0 and 4 was greater for WL-1 than WL-2 gilts (64 to 19 percent versus 33 to 13 percent, line x day, p<.03). In contrast, the decrease in M1F between days 0 and 4 was greater in WL-2 than WL-1 gilts (61 to 6 percent versus 36 to 7 percent, line x day, p<.04). The decline of SF and M1F may be due to a move into the next larger category of follicles or to degeneration (atresia) and disappearance from the surface of the ovaries.

Medium-2 follicles appeared earlier (day 0 versus day 2) in WL-2 than in WL-1 gilts and WL-2 gilts maintained a larger pool of M2F during the early to mid-follicular phase (Table 1). The larger pool of M2F in WL-2 gilts during this period may be a reflection of rapid movement of M1F into the M2F pool between days 0 and 4. The relative percentage of M2F increased between days 0 and 4 in both lines (WL-1, 0 to 29 percent; WL-2, 5 to 46 percent), and then declined to estrus (Figure 3). The loss of M2F was more abrupt in WL-2 than in WL-1 gilts between days 4 and 5 (46 to 21 percent versus 29 to 26 percent, line x day, p<.07).

Some LF had developed on day 3 in both lines and, as expected, the relative percentage of LF increased from day 3 to estrus in both lines (Figure 4). Large follicles accounted for a greater relative percentage of the follicles in WL-1 than WL-2 gilts on days 3 and 4 (day 3, 15 versus 1.9 percent; day 4, 21.9 versus 12.9 percent). The reverse was true after day 4. This resulted from the more rapid increase in LF development in WL-2 gilts between days 4 and 5 (line x day, p<.06). The timing of the rapid increase in LF between days 4 and 5 was related to the timing of rapid decline in M2F in WL-2 gilts and probably reflects the rapid maturation of M2F into LF during this period.

The number of LF observed at estrus tended to differ between the two lines (WL-1, 10.8 versus WL-2, 14.7; p<.1) but did not reflect the expected ovulation rate of either line (Table 2). Both lines must continue selecting ovulatory follicles from the M2F pool

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Table 1. Mean numbers of small, medium and large follicles following PGF2-alpha on day 13 (day 0) of the estrous cycle[a]

		Day 0		Day 2		Day 3		Day 4		Day 5		Estrus	
Follicle[b]	Size (mm)	WL-1	WL-2	WL-1	WL-2	WL-1	WL-2	WL-1	WL-2	WL-1	WL-2	WL-1	WL-2
SF	2 to 2.9	55.7	28.4	33.8	14.5	15.8	15.0	7.4	8.5	7.4	5.5	4.2	3.1
M1F	3 to 4.9	26.1	51.6	32.1	33.3	19.0	26.5	9.0	11.6	4.7	4.5	1.5	1.8
M2F	5 to 6.9	0	4.8	5.7	11.5	13.0	20.0	10.6	21.8	8.4	7.3	6.0	5.8
LF	7	0	0	0.1	0	2.0	1.3	6.6	4.8	8.1	14.9	10.8	14.7

[a]WL-1 = white line gilts which served as randomly selected controls; WL-2 = white line gilts selected for an index of ovulation rate and prenatal survival.
[b]SF, M1F, M2F and LF = small, medium 1, medium 2 and large follicles, respectively.

Table 2. Line differences in number of corpora ablicantia (CA) and larger follicles on estrus following PGF2-alpha on day 13 of the estrous cycle

Line[b]	Follicle Size[a] M2	L	No. CA[c]
WL-1	6.0	10.8	13.8
WL-2	5.8	14.7	20.4

[a]M2F, 5 to 6.9 mm; LF ≥ 7 mm.
[b]WL-1 = white line gilts which served as randomly selected controls; WL-2 = white line gilts selected for an index of ovulation rate and prenatal survival.
[c]Ovulation rate at pretreatment estrus.

in order to achieve final ovulation rates comparable to those, expressed at the previous estrus. All of the M2F in WL-2 gilts and about half of M2F in WL-1 gilts present at estrus must mature into ovulatory follicles to achieve the expected ovulation rates of each line.

Conclusion

Follicular dynamics have changed in response to genetic selection for high prenatal survival and high ovulation rate. WL-2 gilts develop M2-F earlier in the follicular phase and achieve a larger pool of M2-F than WL-1 gilts from which to select LF during the early to mid-proestrous period (day 0 to 4). Large follicles, on the other hand, develop earlier and in greater numbers in WL-1 than in WL-2 gilts during the mid-proestrus period (days 3 and 4). However, between day 4 and day 5 of the proestrous period, a rapid selection and maturation of M2-F into LF occurred in WL-2 gilts. These changes were much less pronounced in WL-1 gilts. Based on the number of large follicles at estrus, WL-2 gilts have achieved only part of their ovulation rate advantage over WL-1 gilts and neither genetic line has developed the number of large follicles needed to achieve expected ovulation rates. Both lines must continue to select follicles from the remaining pool of M2F to achieve expected ovulation rates. Selection rate would have to be much greater in WL-2 than WL-1 gilts (approximately 100 percent versus 50 percent) to achieve the ovulation rate levels of the previous estrus. For this to occur, essentially all of the M2F pool of follicles in WL-2 gilts would have to be healthy and viable. The second phase of this study is designed to compare the health status of different sized follicles in WL-1 and WL-2 gilts during the proestrous period. This research is still in progress.

[1]Hui-Wen Yen is a graduate student and Rodger K. Johnson and Dwane R. Zimmerman are professors in the Animal Science Department.

The Effects of Genetic Line and Diet Regimen on Attainment of Puberty in Gilts*

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Summary and Implications

A trial was conducted to determine the effects of genetic line and gilt development diet regimen and the interaction of these factors on the timely attainment of puberty in gilts. Genetic line was an important factor on the probability of gilts attaining puberty by 8.5 months. Results also indicated leaner gilts (as measured by backfat adjusted to 240 lb) had a lower probability of reaching puberty by 8.5 months than fatter gilts. Gilt development diet regimen and the interaction between genetic line and diet regimen were not significant effects on the attainment of puberty by 8.5 months of age. These results suggest genetic line-specific feeding programs are not necessary for early attainment of puberty.

Introduction

Timely attainment of puberty, the first estrous cycle in gilts, is economically important to a swine operation. With earlier puberty, nonproductive days (from gilt selection to mating) are reduced and gilts can enter the production flow of a swine operation sooner. Additionally, producers can breed gilts on the second or third post-pubertal estrus, rather than on the pubertal estrus, to meet farrowing goals. Mating gilts at second or third estrus can increase litter size at first parity.

Several factors have been suggested to influence age at puberty, including genetics, nutrient content of the diet, feeding levels, reaching a threshold fat/lean ratio in growth, season and level of boar exposure. Most breeding organizations recommend specific gilt development feeding programs for their genetic lines. The purpose of this study was to investigate whether genetic line x gilt development diet interactions exist for timely attainment of puberty in gilts.

Materials

Data for this study came from the National Pork Producers Council's Gilt Development Project. Seven hundred and eight gilts from five genetic lines were assembled using Segregated Early Weaning (SEW) procedures at the Minnesota Pork Producers Association (MPPA) SEW station at Waseca,

Table 1. Number of gilts entering breeding pens by genetic line-diet subclass

	Diet[a]		
Genetic line	1	2	3
A	41	52	40
B	42	40	52
C	44	52	40
D	50	39	39
E	46	40	40

[a]1 = 18% crude protein corn-soybean meal diet provided ad libitum until 250 lb; 2 = 13% crude protein corn-soybean meal 5% added fat diet provided ad libitum until 250 lb; 3 = 21% crude protein corn-soybean meal diet provided ad libitum from 150 to 180 lb and 18% crude protein corn-soybean meal diet fed at 4 lb/day from 180 lb to 180 days of age.

Table 2. Probability of attaining puberty by 8.5 months of age for different genetic lines and diet regiments[a]

Item	Prob. of Puberty	SE[b]
Genetic line		
A	.78 [a*]	.04
B	.70[a,b]	.04
C	.55[c*]	.04
D	.63[b,c]	.04
E	.71[a,b]	.04
Diet[c]		
1	.68	.03
2	.67	.04
3	.68	.03

[a]Estimates with different superscripts differ (P<.05); * = differences P<.001.
[b]Standard error of the mean.
[c]1 = 18% crude protein corn-soybean meal diet provided ad libitum until 250 lb; 2 = 13% crude protein corn-soybean meal 5% added fat diet provided ad libitum until 250 lb; 3 = 21% crude protein corn-soybean meal diet provided ad libitum from 150 to 180 lb and 18% crude protein corn-soybean meal diet fed at 4 lb/day from 180 lb to 180 days of age.

Minnesota. The range in the gilts age was nine days. Lines were chosen to represent a range in body compositional makeup (lean and fat growth rates) and reproductive rates for current genetics available in the U.S. The populations of pigs sampled represented F_1 Hampshire-Duroc, F_1 Yorkshire-Landrace, F_1 Large White-Landrace and two different sources of a three-way cross between Large White, Landrace and Duroc.

When gilts reached 40 to 45 lb, they were moved to the MPPA Swine Testing Station, where they were fed a grower diet (21 percent crude protein) to an average pig weight of 150 lb (approximately 120 days of age). Gilts were then assigned to one of three gilt development diet regimens. These were: 1) ad-libitum feeding of a high protein (18%) corn-soybean meal diet, until they weighed 250 lb, 2) ad-libitum feeding of a low protein (13%), corn-soybean meal diet containing 5 percent added fat until they weighed 250 lb and 3) restricted feeding (4 lb/day) of a high protein (18%), corn-soybean meal diet from 180 lb to 180 days of age. Gilts provided diet regime 3 were given ad libitum access to a 21 percent crude protein grower diet from 150 to 180 lb.

At 180 days, the gilts were moved to a modified open front facility at the station and penned by weight and genetic line. Six hundred fifty-seven gilts entered these pens. The number of gilts per genetic line/diet subclass is shown in Table 1. Gilts were exposed in their own pen and by fenceline contact to young boars once daily. Estrus was detected by using the back pressure test in the presence of a boar. At approximately 200 days, gilts were scanned for backfat with real time ultrasound. Backfat was adjusted to 240 lb using equations in the 1996 Guidelines for Uniform Swine Improvement Programs, National Swine Improvement Federation. Attainment of puberty was scored as: 1 - gilts detected in standing estrus by 8.5 months of age, or 0 - gilts not detected in estrus by 8.5 months of age. Analysis of the data used logits, log [probability of event/(1-probability of event)] and the model included the effects of genetic type, diet regimen and their interaction. A second analysis was done which fit backfat, adjusted to 240 lb, as a covariate in the above model.

Results

The effect of genetic line was significant (P<.001), and gilt development diet and the interaction between genetic line and diet were not important effects for any traits in this analysis. Table 2 presents the estimated probabilities of attaining puberty by 8.5 months of age for the different genetic lines and diet regimes in the trial. Line C had the lowest probability of attaining puberty by 8.5 months of age, line D the highest probability and lines A, B and E were intermediate. The probability of attaining puberty by 8.5 months of age was not affected by how the gilts were fed.

The amount of backfat (adjusted to 240 lb) for gilts in this trial ranged from .40 inch to 1.63 inch. Results of the effect of backfat on attainment of puberty by 8.5 months were in the form of odds ratios. Odds are the probability of an event occurring divided by the probability of it not occurring (odds=P/(1-P)). An odds ratio is the ratio of odds at two different values for the covariate (for example, at .6 inch of backfat and .8 inch of backfat). Results showed that when averaged over all genetic lines and diets, an increase of .2 inch of backfat increased the probability of gilts attaining puberty by 8.5 months of age by approximately 10 percent.

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Effects of Gestation Housing System on Productivity of Three Genetic Lines of Sows

Tom Long
John Halstead[1]

Summary and Implications

A trial was conducted to compare the effects of gestation housing system (outside dirt lots versus inside gestation stalls) and sow genetic line (n=3) on number born alive, litter weaning weight, daily lactation feed disappearance and lactation feed conversion. All sows farrowed and lactated in confinement. No significant interactions were detected between genetic line and gestation housing system. There were no differences between the two gestation housing systems for number born alive and litter weaning weight. However, there were significant differences between sows housed indoors and outdoors for daily lactation feed disappearance and lactation feed conversion. Sows housed outside had a greater daily lactation feed disappearance (1.1 lb/day; P<.01) than those gestated inside. Additionally, outside-housed sows had a poorer lactation feed conversion than inside-gestation sows, the difference being greatest during the summer farrowing season (3.93 versus 3.17; P<.05). Although this trial did not address the added labor and gestation feed costs often associated with housing sows outside during gestation, it did demonstrate some of the fluctuations in efficiency producers may incur housing sows outside during gestation. These points need to be considered when producers consider changes to their current operation.

Introduction

With the numerous changes that have and continue to occur in the domestic pork industry, many producers are re-evaluating all aspects of their operations. Many Nebraska pork producers gestate their sows outside in dirt lots. There is variation among outdoor housing systems for gestating sows in design or layout, number of sows/group and the amount of shelter provided. However, a number of outdoor housing systems share two common features: 1) group feeding of sows and 2) a greater exposure to temperature extremes. As the industry moves towards leaner genetic sow lines in response to consumer demand for leaner pork, the adequacy of outside gestation housing systems for these new lines is questioned. The objective of this study was to compare productivity traits of three genetic lines of sows housed indoors or outdoors during gestation.

Materials and Methods

In this trial, 195 first parity sows from three genetic lines were used. Lines were chosen to represent a range in body compositional makeup (lean and fat growth rates) and reproductive rates for current genetics available in Nebraska. The three genetic lines were: 1) a Large White-Landrace F_1, 2) a three-breed specific cross containing Large White, Landrace and Duroc and 3) a rotational cross comprised mainly of Yorkshire and Hampshire. After weaning their first litter, sows were rebred and assigned across genetic lines to one of two gestation housing systems. The gestation housing systems were: 1) individual gestation stalls, 2 feet x 7 feet, in a climate-controlled breeding/gestation building or 2) outside dirt lots in which 20 sows were housed per pen with access to a straw-bedded shelter. The outside lots contained 20 feeding stalls/pen without lock-in capabilities. During the summer months, mud wallows were made for sows in the outside dirt lots. Sows were maintained in these assigned gestation housing systems through four parities. The primary criteria for culling sows from the trial were failure to rebreed and feet and leg soundness.

Table 1. Number of sows in the trial by genetic line/gestation housing system subclass

	Gestation system	
Genetic Line	Inside	Outside
A	17	18
B	21	23
C	57	59
Total	95	100

The number of sows in each genetic line/housing system subclass is shown in Table 1.

During gestation, sows were fed a .57 percent lysine corn-soybean meal based diet once daily. The amount of feed given to the sows during gestation was adjusted to achieve a similar body condition in all sows. Sows from each gestation housing system were moved to a common farrowing building at approximately 112 days of gestation. After farrowing, sows were fed a common lactation diet (.80 percent lysine) twice daily. The amount of feed given/feeding was increased as rapidly as possible (dependent on the sow's consumption at each feeding) to give sows access to as much feed as they wanted. During lactation, sows were fed in the mornings and late afternoons except during summer farrowing when the second daily feeding was done in the evenings. Season of farrowing was defined as: 1 - (December, January and February), 2 - (March, April and May), 3 - (June, July and August), and 4 - (September, October and November).

Piglets were weighed and weaned, on average, at 21 days of age. Litter weight was adjusted for number after transfer and age at weighing using adjustment factors in the 1996 Guidelines for Uniform Swine Improvement Programs, National Swine Improvement Federation (NSIF). Following weaning, sows were rebred and returned to their gestation housing system. Traits investigated were number born alive (NBA), adjusted 21-day litter weight (A21WT), daily lactation feed disappearance (DF) and lactation

Table 2. **Effects of genetic line, gestation housing system, parity, season of farrowing and the gestation housing system x season interaction on sow productivity traits (NBA-number born alive; A21WT- adjusted 21-day litter weight, lb; DF- daily lactation feed disappearance, lb; LFC-lactation feed conversion)**[g]

Item	NBA	SE[h]	A21WT	SE	DF	SE	LFC	SE
Line								
A	10.9	.34	153.1^{a*}	2.4	14.7^{a}	.40	2.96^{a*}	.09
B	10.7	.27	135.1^{c*}	1.9	13.7^{b}	.32	3.25^{b}	.07
C	10.8	.22	144.8^{b*}	1.5	14.4^{a,b}	.25	3.33^{b*}	.06
Gestation								
Inside	10.9	.22	143.8	1.5	13.7^{a*}	.26	3.03^{a}	.06
Outside	10.7	.24	144.8	1.7	14.8^{b*}	.29	3.32^{b}	.07
Season[i]								
1	11.1^{a}	.24	148.3^{a*}	1.7	14.9^{a*}	.28	3.10^{b*}	.07
2	10.6^{a,b}	.30	148.8^{a*}	2.1	13.9^{b,c}	.36	2.86^{a*}	.08
3	10.1^{b}	.35	132.0^{b*}	2.4	13.5^{c*}	.42	3.55^{c*}	.10
4	11.4^{a}	.33	148.2^{a*}	2.3	14.7^{a,b}	.39	3.21^{b*}	.09
Parity								
2	10.1^{a}	.23	137.8^{a*}	1.6	13.5^{a*}	.27	3.08	.06
3	11.0^{b}	.25	147.0^{b*}	1.8	14.6^{b*}	.30	3.15	.07
4	11.2^{b}	.34	148.2^{b*}	2.4	14.7^{b*}	.40	3.31	.09
Gestation x Season								
Inside 1	11.2	.34	146.5^{a,b}	2.4	14.6	.40	3.02^{a,b,c}	.09
2	10.8	.41	144.2^{b}	2.8	13.5	.48	2.82^{a}	.11
3	9.8	.48	134.6^{c}	3.3	12.8	.57	3.17^{b,c}	.13
4	11.8	.44	149.9^{a,b}	3.0	14.1	.52	3.12^{b,c}	.12
Outside 1	11.0	.33	150.2^{a,b}	2.4	15.2	.40	3.18^{c}	.09
2	10.5	.44	153.4^{a}	3.2	14.3	.53	2.89^{a,b}	.12
3	10.4	.46	129.4^{c}	3.3	14.2	.55	3.93^{d}	.13
4	11.0	.48	146.4^{a,b}	3.4	15.3	.56	3.29^{c}	.13

[g]Estimates with different superscripts differ (P<.05); * = differences P<.01.
[h]Standard error.
[i]1 - (December, January and February), 2 - (March, April and May), 3 - (June, July and August), and 4 - (September, October and November).

feed conversion (LFC). Lactation feed conversion was estimated as lactation feed disappearance from farrowing to 21 days divided by the difference between the litter weight at 21 days and the born alive litter weight. The model for analysis included the effects of genetic line, gestation housing system, parity, season of farrowing and two-way interactions. For the analysis of LFC, number after transfer and age at weighing were also included as covariates in the analysis.

Results and Discussion

Results from this study are presented in Table 2. No significant genetic line x gestation housing system interaction effects were found, indicating the genetic lines would perform/rank similarly relative to each other in the indoor and outdoor housing systems. For NBA, the only significant differences were for parity and season of farrowing. Third and fourth parity sows had more (P < .05) pigs born alive than second parity sows and sows farrowing in the summer had less (P < .05) pigs born alive than sows in other farrowing seasons. Significant effects for 21-day litter weight included genetic line, season of farrowing, parity, and the gestation housing system x season interaction. This significant interaction illustrates the seasonal effect on the two systems of housing for weight of litter produced. During spring, sows housed outside produced heavier (P < .05) litters than sows housed inside, the difference being 9.2 lb. Assuming an economic value of $0.50/lb of 21-day litter weight (NSIF Guidelines, 1996), this difference equaled $4.60/litter in favor of outside-gestated sows.

Significant effects for DF included genetic line, gestation housing system, season of farrowing and parity. Sows housed outside had greater (P < .05) lactation feed disappearance than sows housed inside. Significant effects for LFC were genetic line, gestation housing system, season of farrowing and the interaction between gestation housing system and season. Sows gestated outside were less (P < .05) efficient at using feed for litter weight gain (LFC) than sows housed inside. This was especially true during the summer farrowing season. Outside-housed sows in the farrowing house during the summer used .76 lb more feed per pound of 21- day litter weight gain than inside-gestated sows. Assuming an average weaning weight of 130 lb and $0.07/lb lactation feed costs, this loss in efficiency would be $6.92/litter.

Conclusion

These results suggest producers can attain similar output levels from the sow herd (as measured by NBA and A21WT) with either outdoor and indoor gestation accommodations. This trial did not address the added labor and gestation feed costs often associated with housing sows outside during gestation, but it did indicate some of the fluctuations in efficiency producers could face gestating sows outside and the effects season can have on sow reproductive performance.

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Responses to 14 Generations of Selection for Components of Litter Size

Rodger Johnson[1]

Summary and Implications

Eleven generations of selection for increased index of ovulation rate and embryonal survival rate, followed by three generations of selection for litter size, were practiced. Laparotomy was used to count corpora lutea and fetuses at 50 days of gestation. High indexing gilts, approximately 30 percent, were farrowed each generation. All gilts in these litters were mated to boars selected from litters of gilts in the upper 15 percent of the distribution for index. Selection from generation 12 to 14 was for increased number of fully formed pigs. Replacement boars and gilts were selected from the largest 25 percent of the litters. Total response in the selected line compared to the control was approximately 6.7 ova, 3.9 fetuses, 3 fully formed pigs, and 1.4 live pigs (P < .01) at birth. Ovulation rate and number of fetuses had positive genetic correlations with number of stillborn and mummified pigs, which increased with selection for the index. Approximately 77 percent of the increase in fetuses was represented by a pig at birth, and 36 percent of the increase was a live pig. Average pig birth weight declined as litter size increased. Smaller pigs, and the higher rate of inbreeding in the select line, may have contributed to greater fetal losses in late gestation, greater number of stillborn pigs and lower preweaning viability in the select line. Phenotypic variation in litter size and its component traits is high. Heritabilities were between 10 and 25 percent; sufficient genetic variation exists to increase litter size with selection. Response in total born per litter was approximately 15 percent greater than response predicted from direct litter size selection. This is probably not enough to justify implementation of this procedure in industry breeding programs. Because of undesirable genetic relationships between ovulation rate and the number of stillborn and mummified pigs and decreased birth weight with increased litter size, genetic improvement programs should emphasize live born pigs and perhaps weight of liveborn pigs in selection programs.

Introduction

Reproductive efficiency is one of the most important variables in economic efficiency of swine enterprises. Litter size, the most important reproductive trait, is weighted heavily in development of maternal lines.

Economic value of litter size relative to other traits will likely increase in the future due to decreasing emphasis on leanness as a result of successful genetic selection for decreased backfat. Swine breeders must have reliable information on genetic parameters for litter size and its components to develop optimum breeding strategies. Correlated responses expected in pig weights, survival and litter weaning weights from continued selection for increased litter size and its components must be known.

In 1981, an experiment began to select for increased index of ovulation rate and embryonal survival at 50 days of gestation. After 10 generations, index selection was discontinued and selection for increased litter size was practiced. This report presents results of 14 generations of selection. Responses in litter size and its component traits litter birth weights, and litter weaning traits are presented.

Methods

The population was a composite of the Large White and Landrace breeds. Boars and gilts of each breed were reciprocally crossed in 1979 to make a population with 50 percent of genes from each breed. Random mating was practiced for two generations to reduce linkage relationships created in the F_1 cross. Then select (Line I) and control (Line C) lines were formed by randomly assigning littermates to lines. Lines were maintained as closed populations with generation interval of one year.

Line I was selected 10 generations for increased index followed by one generation of random selection (generation 11) and three generations of selection for increased number of fully formed pigs at birth (generations 12-14). The index included number of corpora lutea as a measure of ovulation rate (OR) and the ratio of fetuses (F) to OR (F/OR) at 50 days of gestation. The index was constructed to make maximum expected change in litter size. The index used from generations 0 to 5 was I_1 = 10.6 x OR + 72.6 x F/OR. Because of the increase in OR during the first five generations, the index was changed to place more emphasis on embryonal survival rate. The index used from generations 6 to 10 was I_2 = 9.9 x OR + 148.6 x F/OR.

Laparotomy was performed at 50 days of gestation in all pregnant Line I gilts (n = 1,618) and a random sample of one-half of Line C gilts(n = 269). Uteri and ovaries were exposed and number of corpora lutea and fetuses were counted. The index was calculated and the highest ranking Line I gilts (45 to 55 per generation) were selected. The remainder were culled before parturition. The number of litters during generations 0 to 10 was 43 to 53 in Line I, and 36 to 44 in Line C.

Two sons of each of the 15 Line I dams with greatest index values were selected. One boar from each litter and two from the five highest indexing dams were used as breeders; the remaining boars were alternates and used only if primary boars died or failed to breed.

Approximately 30 boars and 55 gilts in Line C were selected. Of the 55 gilts, one gilt was selected randomly from every litter and one additional gilt was selected from randomly chosen litters. Two boars were selected from each paternal half-sib family (15 families per generation); one was designated as a breeder, the other an alternate.

Index selection was terminated after 10 generations, but generation 10 Line I gilts that farrowed were a selected sample. A random sample of their progeny, the generation 11 gilts, was selected, mated and farrowed to estimate selection response in litter size in unselected gilts in which laparotomy had not been performed. However, because their sires were selected on the index, the total index selection applied was calculated through generation 11. There were 60 Line I litters in generation 11.

Selection during generations 12-14 in Line I was based on number of fully formed pigs in the litter in which pigs were born. Two boars, a primary breeder and an alternate, were selected from each of the 15 largest litters. All gilts from the largest litters were selected until the desired number was attained. Number of litters in Line I was increased at generation 13. There were 47, 79 and 97 Line I litters by generations 12, 13, and 14 dams, respectively. These dams were selected from 15, 22 and 28 litters, respectively.

Table 1. Difference in realized cumulative selection differentials between Lines I and C [a]

Gen	I	OR	F	ES
1	12.7	1.1	1.13	0.01
2	33.7	3.15	2.47	0.00
3	50.8	4.97	3.37	-0.02
4	71.4	6.67	5.20	0.01
5	95.9	9.04	6.69	0.00
6	115.5	10.52	7.72	0.01
7	130.0	12.29	9.36	0.00
8	150.5	14.05	11.07	0.02
9	182.3	17.15	12.43	0.02
10	217.1	21.75	13.44	0.00
11	257.9	25.51	14.73	-0.02

[a]Gen = generation, I = Index, OR = number of corpora lutea, F = number of fetuses, and ES = embryonal survival rate.

Management of pigs

Pigs were transferred among litters both within and across lines within two days of birth. The objective was to give each sow between eight and 11 pigs to nurse, which was accomplished for 73 percent of litters; 12 percent of the sows had fewer than eight pigs after transfer, 15 percent had more than 11.

Pigs were weaned at 28 days of age through generation 12 and approximately 12 days of age for generations 13 and 14. Pigs were moved to nursery rooms at weaning where they stayed to approximately 56 days of age when selections were made. Selected pigs were moved to naturally ventilated buildings with 10 pigs per pen. Boars and gilts were in separate buildings.

Estrus detection in gilts began on the day the oldest pig in each pen reached 130 days of age. After expressing their pubertal estrus and the subsequent estrus, they were moved to a breeding building. The objective was to mate gilts at their third or later estrus. Gilts averaged approximately 250 days of age when mated. Some gilts were mated at their second estrus and, in a few cases, at their pubertal estrus. A total of 2,510 gilts were mated and became pregnant during the experiment, 33 were mated at their pubertal estrus and 58 at their second estrus. Gilts were mated each day they were in estrus. They were in stalls during gestation.

Standard corn- or milo-soybean meal diets, balanced to meet nutrient requirements for age and production status of pig, were used. Pigs were provided ad libitum access to feed until they were approximately 180 days of age (gilts) or 160 days of age (boars), after which they were given approximately 5 lb feed per day until mating. Gilts were given 4.6 lb of feed per day during the gestation period, except during the last 14 days when the amount was increased to 5.5 lb. Sows had ad libitum access to feed during lactation.

Traits measured

The traits measured at 50 days of gestation were number of corpora lutea and number of fetuses. Embryonal survival and index were calculated from these values. Number of fully formed pigs, number of live pigs, number of stillborn pigs, number of mummified pigs and weight of all fully formed pigs were recorded at birth. Nurse dam was recorded for all pigs transferred to another litter. Each pig was weighed when weaned.

Traits included in the analyses were OR, F, F/OR, total born per litter (TB), number born alive per litter (NBA), number of stillborn pigs (SB), number of mummified pigs (MUM), total weight of fully formed pigs at birth (LBW), number of pigs weaned (NW) and total weight of pigs weaned by each sow (LWW). All records were considered a trait of the gilt.

Data analyses

Appropriate statistical procedures were used to estimate genetic parameters and responses in each trait. The analyses performed produced estimated breeding values for each animal, using all pedigree information. Mean breeding values were calculated for each line and plotted to illustrate selection responses. Responses in both Line I and C were estimated with regressions of breeding values on generation and by contrasts among breeding values for specific generations.

Results

Cumulative selection differentials for Index and for component traits are in Table 1. Relative to Line C, total selection applied in Line I accumu-

(Continued on next page)

lated to 257.9 Index points, 25.5 ovulations, 14.7 fetuses at 50 days gestation, and -.02 embryonal survival rate.

Number of observations and phenotypic means for traits at 50 days of gestation are in Table 2. The difference between Lines I and C at generation 10 was 6.7 OR, 3.3 F and -.04 ES. Mean estimated breeding values are plotted in Figure 1. Estimated genetic responses in Line I relative to Line C averaged .67 OR (P<.01), .35 F (P<.01) and -.008 ES (P<.05) per generation. Expected responses based on base generation parameter estimates were an increase in ovulation rate and a slight decline in embryonal survival rate, which was expected to maximize the response in litter size. The observed results at 50 days gestation agreed well with expected responses.

Number of litters and phenotypic means for birth and weaning traits are in Table 3. The estimated genetic difference between Line I and C at generation 10 was 3.1 pigs. However, the difference in number born live was 1.6 pigs. The differences in generation 11, which represented total index selection applied and a random sample of gilts selected to farrow, were 1.3 fully formed pigs and .4 pigs born live. Litter birth weight tended to be greater for Line I; however, the difference between lines did not increase significantly with generations.

Number of stillborn and mummified pigs per litter were greater in Line I than Line C each generation during index selection. The differences were 1.51 stillborn and .83 mummified pigs at generation 10 and .93 stillborn and .53 mummified pigs at generation 11. Part of the increase in number of mummified pigs was due to the laparotomy procedure. The effect of laparotomy was estimated to be a reduction of .97 ± .26 fully formed pigs, .81 ± .26 pigs born live, and increase of .44 ± .12 mummified pigs. The difference in this effect on fully formed and mummified pigs is due to fetal deaths occurring after 50 days gestation and not detected as a mummified pig at birth. The laparotomy procedure did not significantly affect number of stillborn

Table 2. Means for traits[a] at 50 days gestation[b]

	N		OR		F		ES	
Gen	I	C	I	C	I	C	I	C
0	128		13.98		10.81		0.79	
1	127	23	14.31	13.04	11.15	9.57	0.79	0.74
2	132	24	15.11	14.32	10.85	10.96	0.73	0.78
3	148	23	15.76	14.35	11.56	10.48	0.74	0.74
4	150	21	15.95	13.24	11.49	9.52	0.73	0.73
5	127	43	17.02	14.02	11.89	10.91	0.71	0.78
6	164	22	17.98	13.09	12.70	9.91	0.73	0.84
7	169	24	18.87	14.46	13.03	11.29	0.73	0.79
8	155	22	21.23	14.41	13.08	9.73	0.67	0.69
9	156	19	20.70	13.00	12.99	10.00	0.67	0.79
10	162	48	20.46	13.77	13.64	10.33	0.72	0.76

[a] N = number of gilts, OR = number of corpora lutea, F = number of fetuses, ES = embryonal survival rate, I = Index select line, and C = control line.
[b] Laparotomy not done on base generation Line C gilts.

pigs. There was a reduction in number of mummified pigs in both lines during generations 11 to 14 when laparotomy was not practiced.

Genetic response in Line I relative to Line C over all generations averaged an increase of .21 ± .04 fully formed pig, .10± .04 live pig, .12± .03 stillborn pig, .03 ± .02 mummified pig and .2 ± .13 lb litter birth weight per generation (Figures 2 and 3). Responses were significant except those in mummified pigs and litter birth weight. Multiplying these values by 14 generations of selection produces predicted genetic responses of 2.95 fully formed and 1.4 live pigs. Mean differences during generations 12 to 14 were somewhat greater than these values, averaging 4.1 total and 2.1 live pigs per litter.

Mean number of pigs weaned and litter weaning weight are in Table 4. Means are adjusted for number after

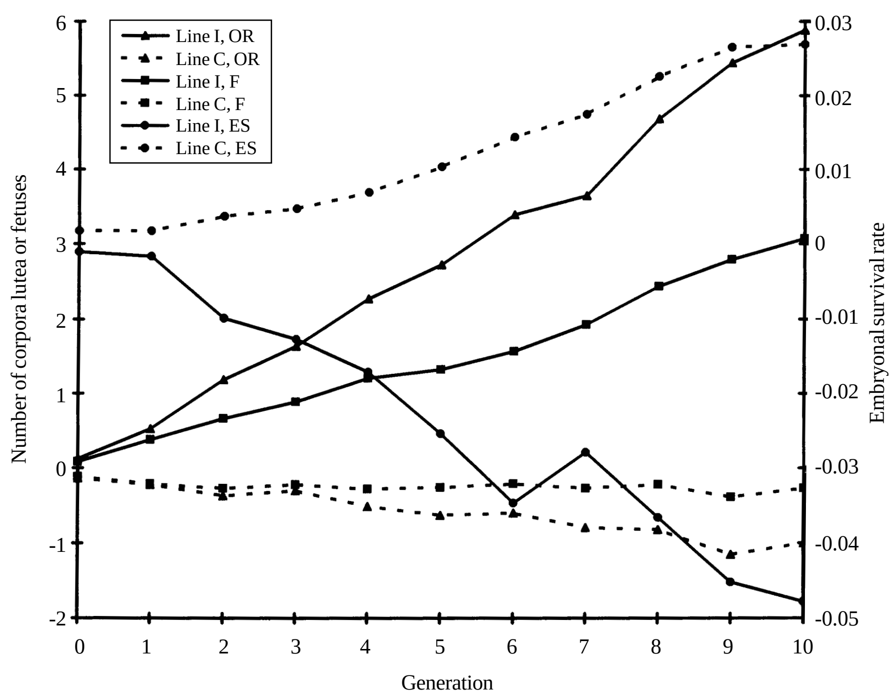

Figure 1. Mean estimated breeding value plotted against generation (genetic trend) for ovulation rate (OR), number of fetuses at 50 days gestation (F), and embryonal survival to 50 days gestation (ES).

Table 3. **Mean number of fully formed (FF), live (NBA), stillborn (SB), and mummified (MUM) pigs, and weight of FF pigs at birth (LBW)[a]**

	No litters		FF		NBA		SB		MUM		LBW, lb	
Gen	I	C	I	C	I	C	I	C	I	C	I	C
-1	42	41	10.3	9.5	9.9	9.3	0.43	0.22	0.17	0.05	29.7	28.6
0	43	41	11.0	10.4	10.5	10.2	0.49	0.20	0.56	0.24	30.8	28.8
1	43	40	10.8	9.1	10.3	8.8	0.56	0.25	0.95	0.38	20.4	24.2
2	44	42	10.5	9.3	9.7	8.9	0.75	0.41	1.34	0.67	27.1	25.1
3	44	42	10.6	8.3	9.3	8.0	1.23	0.34	1.86	1.17	26.2	22.4
4	44	43	10.7	8.9	9.0	8.6	1.75	0.30	1.20	0.61	27.5	24.6
5	48	43	11.6	9.2	9.8	8.2	1.79	1.00	1.56	1.21	27.5	24.4
6	44	44	11.7	9.8	10.1	9.1	1.57	0.70	2.57	0.31	29.5	29.3
7	45	41	11.6	10.0	10.4	9.2	1.20	0.78	1.76	0.63	26.2	27.5
8	51	42	11.2	8.1	9.2	7.6	2.04	0.53	1.65	0.50	25.1	21.6
9	47	36	11.8	9.3	10.2	8.6	1.62	0.76	1.55	0.21	24.9	25.1
10	53	39	12.6	9.5	10.7	9.2	1.87	0.36	1.19	0.36	26.6	24.0
11	60	47	11.2	9.4	9.6	9.2	1.65	0.72	0.70	0.17	26.4	25.1
12	47	41	13.8	9.8	11.5	9.0	2.30	0.80	0.60	0.46	31.5	25.1
13	79	47	13.3	8.8	10.4	8.5	2.90	0.30	0.49	0.17	30.1	23.3
14	97	43	13.4	9.7	11.4	9.3	2.05	0.37	0.47	0.30	29.7	24.6

[a]Gen = generation, I = index select line, C = control line.

crossfostering and weaning age. Records for sows whose pigs were all fostered to other sows were not included. Sows given pigs to nurse and all pigs subsequently died were given a value of zero for both traits. Another line farrowed contemporary to these lines and fostering was practiced across all three lines. Thus, number nursed was less than number of live pigs for Line I. There was a tendency for Line I sows to wean fewer pigs with less weight at weaning than Line C sows. Average response in Line I relative to Line C was -.05 ± .02 (P < .05) pigs weaned and -.4 ± .42 lb litter weight per generation (Figure 4).

Estimates of genetic parameters are in Table 5. Heritabilities ranged from .08 for number weaned to .32 for litter birth weight. Heritabilities of number of fetuses, number of fully formed pigs, number of live pigs and number of stillborn pigs were from .16 to .18. Heritability of number of mummified pigs was .12. All values are somewhat greater than most values found in the literature, which for these traits are mostly in the range of .05 to .15.

Ovulation rate was negatively correlated with embryonal survival but positively correlated with number of fetuses, number of fully formed pigs, number of stillborn pigs and number of mummified pigs. It was not correlated with number of live pigs, but was negatively correlated with number weaned. Embryonal survival was positively correlated with number born but was not correlated with other traits. Number of fetuses was positively correlated with total born and live pigs at birth. Number of stillborn pigs also was positively correlated with number of fetuses.

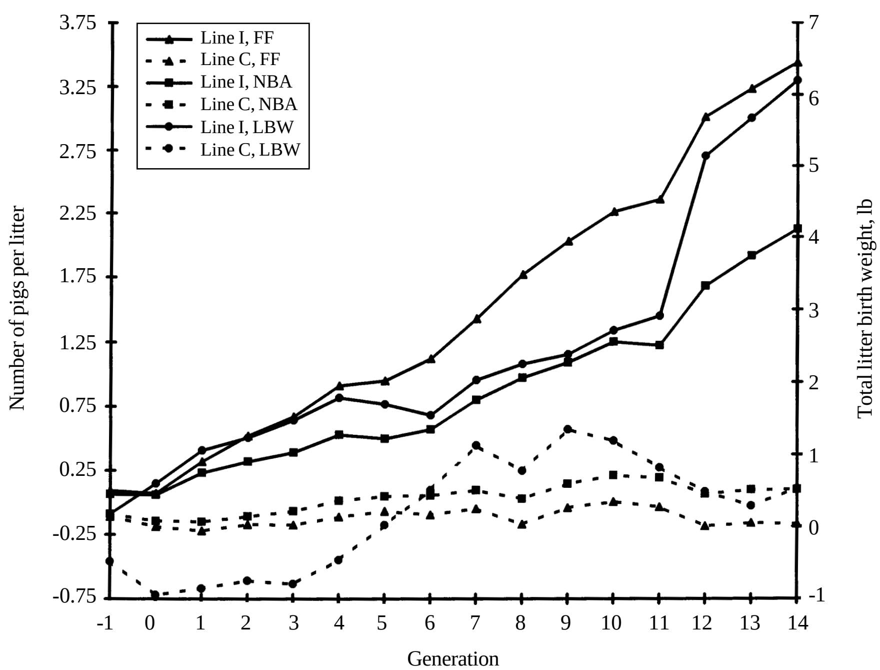

Figure 2. Mean estimated breeding value plotted against generation (genetic trend) for number of fully formed pigs (FF), number of live pigs (NBA), and weight of fully formed pigs (LBW) at birth.

Discussion

The selection index was designed to maximize litter size response. This result probably was achieved for number of fetuses at 50 days gestation, but response in litter size at birth was less. The response in number of fetuses was .35 per generation, approximately 30

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Table 4. **Mean number weaned per litter and total weight of litter weaned, adjusted for number after crossfostering and weaning age[a]**

Gen	Number weaned per litter		Litter weaning weight, lb	
	Line I	Line C	Line I	Line C
-1	8.2	8.4	124.7	132.0
0	9.4	9.2	132.0	128.5
1	8.1	7.6	111.1	108.5
2	8.2	8.3	117.7	119.5
3	7.8	8.4	115.7	124.3
4	8.2	8.2	116.2	114.8
5	8.3	8.3	119.7	114.4
6	8.6	8.9	115.5	121.0
7	8.4	9.0	108.5	119.9
8	7.9	8.6	111.1	119.7
9	8.1	8.5	103.6	113.3
10	8.5	8.9	105.2	115.7
11	8.1	8.3	111.1	107.1
12	8.3	9.0	51.3	57.2
13	8.3	9.2	55.4	60.5
14	8.6	9.6	58.1	66.0

[a]Gen = generation, Line I = index select line, Line C = control line.

percent greater than expected response for selection directly on number of fetuses. However, the response in number born per litter was .21 pig per generation, approximately 15 percent greater than response expected from direct selection for litter size, but only 60 percent of the observed response in number of fetuses.

When the experiment was designed, we believed most embryonal/fetal loss had occurred by 50 days gestation and that number of fetuses and litter size were highly correlated. Since then, researchers at the US Meat Animal Research Center reported significant fetal loss occurs late in gestation. This experiment verifies those results. Increased number of mummified pigs and losses of fetuses after 50 days gestation occurred in Line I. The losses were greater in sows carrying larger numbers of fetuses. Genetic improvement in uterine capacity after 50 days of gestation did not keep pace with the increase in number of fetuses and late gestation losses increased.

Table 5. Heritabilities and genetic correlations

Trait	Heritability	Genetic correlation		
		OR	F	ES
OR	0.24			
F	0.18	0.44		
ES	0.14	-0.86	0.47	0.14
FF	0.16	0.24	0.85	0.36
NBA	0.17	-0.02	0.61	0.36
SB	0.17	0.34	0.67	-0.01
MUM	0.12	0.27	0.17	0.00
LBW	0.32	-0.10	0.47	0.24
NW	0.08	-0.37	-0.18	0.07
LWW	0.25	-0.18	0.12	0.16

[a]OR = number of corpora lutea, F = number of fetuses, ES = embryonal survival, FF = total number of pigs born per litter, NBA = number born alive, SB = number of stillborn pigs, MUM = number of mummified pigs, LBW = litter birth weight, NW = number weaned, and LWW = litter weaning weight.

All expressions of litter size, including number of stillborn and mummified pigs, had greater heritabilities than most values in the literature. Greater genetic variation for these traits in this population may be due to the selection response in ovulation rate. As ovulation rate increased, uterine capacity became the limiting variable in litter size. Measures of litter size are, then, measures of effects of uterine capacity on fetal survival rate, especially those in late gestation. Selecting on component traits of litter size probably would have been more effective if ovulation rate and a measure of uterine capacity to term were used.

Two other important findings in this study are the correlated responses of increased number of stillborn pigs and decreased number weaned in Line I. Increased incidence of stillborn pigs seems partly related to birth weight. Averaged over generations, birth weight of live pigs averaged 2.46 lb in Line I and 2.73 lb in Line C. Average birth weight of stillborn pigs was less than weight of live pigs in both Line I and C (.51 and .42 lb, respectively). This difference between live and stillborn

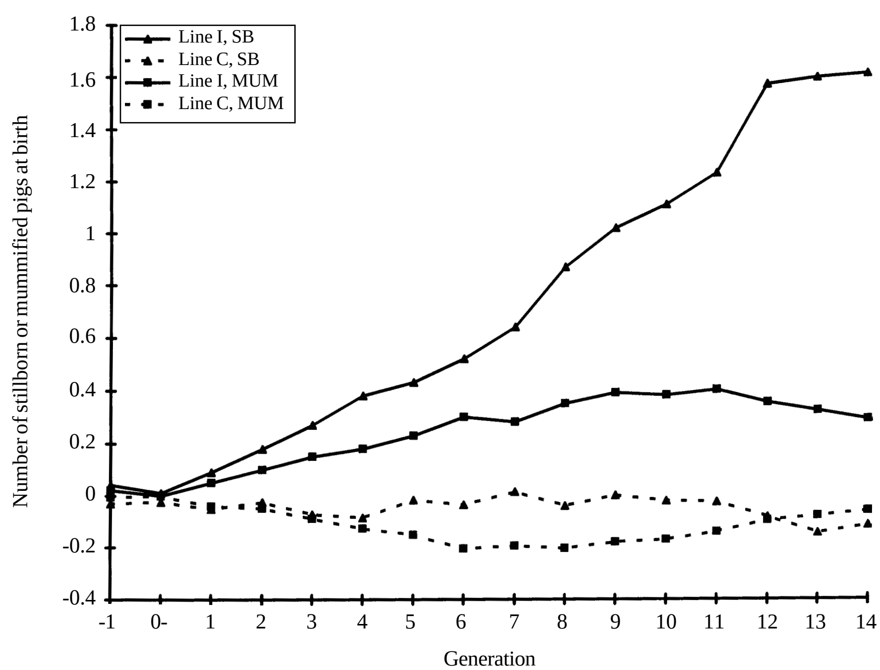

Figure 3. **Mean estimated breeding value plotted against generation (genetic trend) for number of stillborn (SB) and mummified pigs (MUM) per litter.**

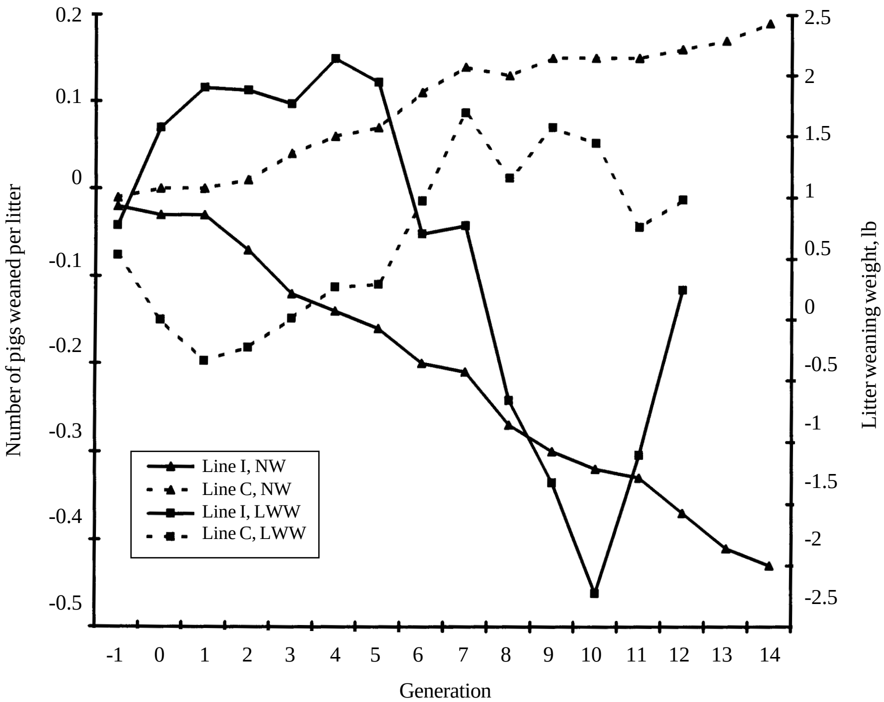

Figure 4. Mean estimated breeding value plotted against generation (genetic trend) for number of pigs weaned (NW) and 28-day litter weaning weight (LWW).

pigs remained consistent throughout the experiment. Average birth weight decreased in Line I with selection for increased litter size. Therefore, there were more small pigs and more of them were stillborn. Other factors, such as length of parturition, which may be longer in large litters, also may be involved in the increase in stillborn pigs.

Decreased weight of live pigs might have contributed to greater preweaning mortality in Line I. Although crossfostering was practiced, Line I sows frequently nursed only Line I pigs. If birthweight was related to viability, more deaths of Line I pigs were expected. Survival rate from birth to weaning was analyzed, including the genetic effect of the pig and of its nurse dam. Direct heritability, that due to genes of the pig, was 3 percent, whereas maternal heritability, that due to genes of the nurse dam, was 7 percent. The trend in breeding values was negative for both components in Line I. The combination of decreased genetic trend in both direct and maternal effects on pig survival caused the significant negative trend in number weaned. Selection did not significantly affect maternal effects on milk production as measured by litter weaning weight.

Inbreeding increased in both lines during the experiment, but it increased more in Line I. Mean inbreeding in generation 14 was .18 (range from .15 to .26) in Line I and .12 (range from .09 to .17) in Line C. Increased inbreeding of both dam and pig are known to decrease pig viability. Therefore, the decrease in pig survival to weaning and decrease in number weaned in Line I were likely related to both decreased birth weight and to increased inbreeding.

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Activity of Four Antimicrobial Agents Against Porcine *Serpulina pilosicoli* Isolates From the Midwestern United States

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Summary and Implications

Porcine colonic spirochetosis (PCS) is a non-fatal, diarrheal disease affecting pigs during the growing and finishing stages of production. The disease is caused by Serpulina pilosicoli, a newly recognized species of intestinal spirochetes. Because Serpulina pilosicoli is transmitted by the fecal-oral route, control measures aimed at reducing environmental contamination, including sanitation and antimicrobial therapy, should be investigated. We determined the antimicrobial susceptibility of seven porcine Serpulina pilosicoli isolates recovered from pigs in the midwestern United States against four antimicrobials commonly used for control of swine dysentery, a disease caused by the related spirochete, Serpulina hyodysenteriae. All the isolates were susceptible to carbadox and tiamulin, whereas the percentages of isolates susceptible, intermediate and resistant were 66.6, 16.6 and 16.6 percent with lincomycin, and 50 percent susceptible and 50 percent resis-

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tant with gentamicin. This information is consistent with field observations about the efficacy of the respective antimicrobials for control of PCS.

Introduction

Porcine intestinal spirochetes consist of at least three species in the genus *Serpulina*; *Serpulina hyodysenteriae*, the agent of swine dysentery, *Serpulina innocens*, a non-pathogenic spirochete of the swine colon and the newly recognized *Serpulina pilosicoli*, the agent of porcine colonic spirochetosis (PCS). Clinical signs of *Serpulina pilosicoli* infection consist of transient-to-persistent watery to mucoid green to cement gray cow-manure-like diarrhea without blood, usually occurring 10 to 14 days after mixing grower pigs from different sources. While up to 50 percent of the pigs may show diarrhea, morbidity varies greatly from farm to farm and the factors responsible for this variation are not completely understood. Although the diarrhea associated with PCS usually subsides, the concurrent depression of weight gains results in unevenness within affected groups. This is a major problem in all in/all out management systems in which PCS causes disruption of pig flow by both extending the marketing period and increasing the number of pigs with lighter weights.

Because transmission of *Serpulina pilosicoli* is by the fecal-oral route, control measures aimed at reducing environmental contamination, including sanitation and antimicrobial therapy, should provide adequate disease control. Since *Serpulina pilosicoli* is a newly identified intestinal spirochete, determining the antimicrobial susceptibility of this organism so disease-specific control strategies can be implemented is important. In this study, we determined the antimicrobial susceptibility of seven porcine *Serpulina pilosicoli* isolates against four antimicrobials commonly used to treat swine dysentery. The *Serpulina pilosicoli* were isolated from pigs on farms in the midwestern United States.

Materials and Methods

A total of seven isolates of *Serpulina pilosicoli* were obtained from rectal swabs or colonic scrapings taken from pigs on farms in Iowa (*n* = 2), Missouri (*n* = 3) and Nebraska (*n* = 1). All the isolates were from different farms except isolates UNL-53 and UNL-54, which were both obtained from one farm in Missouri (Table 1). After isolating the spirochetes by anaerobic culture on selective medium, representative isolates were characterized using a polymerase chain reaction amplification method specific for *Serpulina pilosicoli*. The minimal inhibitory concentrations (MIC) of carbadox, gentamicin, lincomycin and tiamulin against the *Serpulina pilosicoli* isolates were determined by an agar-dilution method.

Results

The MIC of carbadox, gentamicin, lincomycin and tiamulin against each *Serpulina pilosicoli* isolate is presented in Table 1. Because isolates UNL-53 and UNL-54 were obtained from the same farm and had the same MIC values, they were considered one for the calculations of the MIC of each antimicrobial effective against 50 percent (MIC_{50}) and 90 percent (MIC_{90}) of the isolates (Table 2). From available literature data on the antimicrobial susceptibility breakpoints of *Serpulina hyodysenteriae* for each antimicrobial, we estimated all of the *Serpulina pilosicoli* isolates were susceptible to carbadox and tiamulin. However, the percentages of isolates susceptible, intermediate and resistant were 66.6, 16.6 and 16.6 percent with lincomycin, and 50 percent susceptible and 50 percent resistant with gentamicin.

Discussion

The results from this study indicate the pattern of antimicrobial susceptibility of midwestern porcine *Serpulina pilosicoli* to antimicrobials used for treatment of swine dysentery was similar to that of *Serpulina hyodysenteriae*. Because of this, control measures known to be effective for swine dysentery, including stress reduction, sanitation and medication of

Table 1. Minimal inhibitory concentration values (μg/ml) of four antimicrobials against *Serpulina pilosicoli* isolated from pigs on farms in the midwestern United States

Isolate	Origin†	Carbadox	Gentamicin	Lincomycin	Tiamulin
UNL-5	Iowa	<0.0005	1.0	25.0	0.50
B1555a	Iowa	<0.0005	1.0	12.5	0.05
UNL-53	Missouri	0.015	10.0	75.0	0.10
UNL-54	Missouri	0.015	10.0	75.0	0.10
UNL-55	Missouri	0.005	10.0	25.0	0.05
B359	Missouri	<0.0005	1.0	12.5	0.20
UNL-8	Nebraska	0.005	10.0	50.0	0.05

†All isolates are from different farms except for isolates UNL-53 and UNL-54 which are from the same farm.

Table 2. Minimal inhibitory concentration (MIC) values of four antimicrobials against *Serpulina pilosicoli* isolates obtained from pigs on farms in the midwestern United States

Antimicrobial	Drug concentration range (μg/ml)	MIC_{50}	MIC_{90}
Carbadox	<0.0005 - 0.015	<0.0005	0.015
Gentamicin	1.0 - 10.0	1.0	10.0
Lincomycin	12.5 - 75.0	25.0	75.0
Tiamulin	0.05 - 0.50	0.05	0.50

water and feed with *Serpulina hyodysenteriae*-specific antimicrobials should be effective against PCS caused by *Serpulina pilosicoli.*

Koch's postulates for *Serpulina pilosicoli* have been fulfilled using gnotobiotic pigs and conventional pigs. Following initial association with the cecal and colonic mucus gel, the spirochetes attach to the colonic enterocytes, residing in the brush border of the colonic cells where they damage the microvilli, causing reduced surface area and perhaps loss of absorptive function. Clinical signs of absorption failure or diarrhea may be seen when the reserve capacity of the large intestine is compromised sufficiently. With time, the disease progresses to a stage in which the balance between infection and host response determines whether the pig remains persistently infected or eliminates the spirochetes. Pigs persistently infected with *Serpulina pilosicoli* develop chronic inflammation of the large intestine. The following altered intestinal function is thought to result in reduced growth rate.

Serpulina pilosicoli can be isolated from the large intestine of challenge-inoculated pigs for up to six weeks post-inoculation, even though diarrhea may have ceased. This suggests transmission of PCS is from shedding of *Serpulina pilosicoli* in the feces of persistently infected pigs. Some pigs infected with *Serpulina pilosicoli* may recover naturally without medication, but they have reduced average body weight gain when compared with noninfected control pigs. Carrier-shredder pigs are an important reservoir of *Serpulina pilosicoli* on infected farms and the movement of these pigs is the most likely means of transmission of *Serpulina pilosicoli* between farms. Management systems favoring fecal-oral recycling, such as open-flush gutters and recycled lagoon water, appear to promote maintenance and transmission of PCS. Thus, in all in/all out multi-site production systems, transmission is most likely from co-mingling susceptible and carrier-shredder pigs or from the contaminated environment. In continuous flow production systems, spirochetes are most likely transmitted when younger *Serpulina pilosicoli*-naive pigs come into contact with feces of older pigs. The possibility also exists that hosts other than pigs, such as dogs, rodents and wildlife, including birds, act as sources of PCS infection, emphasizing the need for biosecurity.

Diarrheal disease and reduced performance associated with*Serpulina pilosicoli* have been reported from all major swine producing countries in North America, Europe and Australia. We estimated a 50 percent prevalence rate of *Serpulina pilosicoli* infection in finisher facilities within a multi-site production system in the United States; a finding not unlike the prevalence of *Serpulina hyodysenteriae* several years ago, before control measure for this spirochete became widely available.

The results of antimicrobial susceptibility of midwestern isolates of porcine *Serpulina pilosicoli* suggested carbadox and tiamulin may be suitable for control of PCS. Conversely, the susceptibility of the isolates to lincomycin and gentamicin was variable. Although field information is consistent with these laboratory results, the applicability of specific antimicrobials in controlled challenge studies would be helpful in making cost-effective recommendations for prevention or treatment of PCS. When response to treatment is poor, (*I*) error in dosage and/or inadequate delivery of antimicrobials, (*ii*) combination of agents with different antimicrobial susceptibility or (*iii*) poor control of environmental contamination may be involved. Eradication of *Serpulina pilosicoli* with antimicrobial therapy and sanitation with or without depopulation is probably possible, but it might not be cost-effective. When PCS occurs concurrently with other cause(s) of diarrhea, such as viruses, other bacteria, intestinal parasites or other non-infectious causes, mortality is high. In these cases, thorough laboratory diagnostic investigation is needed in order to achieve adequate control.

It is known that *Serpulina pilosicoli* has a broader host range than *Serpulina hyodysenteriae*. Spirochetes similar to *Serpulina pilosicoli* have been seen in the intestines of humans, non-human primates, dogs, guinea pigs, opossums, mice and birds often with clinical signs or lesions of colonic spirochetosis. Because *Serpulina pilosicoli* has been isolated from humans with lesions similar to PCS and human *Serpulina pilosicoli* can colonize in pigs and produce colitis, it may be zoonotic and have public health significance.

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Protein Sources for Segregated Early Weaned (SEW) Pigs

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Summary and Implications

Three experiments were conducted to examine different protein sources for segregated, early weaned (SEW) pigs. Protein sources evaluated included extruded soybeans, extruded-expelled soybeans, solvent-extracted soybean meal and spray-dried egg product as a substitute for spray-dried plasma protein. Performance differences among the four treatments could not be detected after seven weeks (two-week experimental period and five-week common corn-soybean meal diet). The cost of gain was reduced during the two-week treatment period by feeding diets with reduced plasma protein levels with or without the partial or complete substitution of spray-dried egg product. In addition, SEW pigs consuming the diet containing 20 percent soybean meal and 6 percent spray-dried plasma performed similarly to pigs receiving a more conventional SEW nursery diet (10 percent soybean meal, 6 percent spray-dried plasma protein). These experiments suggest egg protein and soybean proteins may be used for SEW pigs without significantly decreasing nursery performance over a seven-week period. The role of plant protein sources in diets for SEW pigs needs to be reevaluated.

Introduction

Early weaning at 14 to 18 days of age, is becoming increasingly common in the pork industry. Research has been directed toward easing the transition from sows' milk to dry feed in order to minimize lags in postweaning pig performance. It has been suggested two proteins present in soybeans, glycinin and beta-conglycinin, may cause a hypersensitivity response in pigs and decrease in performance. Conventionally processed, commercial soybean meal may retain some antigens that cause this transient hypersensitivity in pig. When soybeans are extruded, however, the concentrations of these antigens can be reduced to low levels which may lead to improvements in growth performance. In addition, the price and availability of some high-quality protein sources, such as egg processing by-products, are becoming favorable for inclusion into nursery diets. The objective of this study was to determine whether blood plasma products in diets for SEW pigs could be replaced by alternative, less expensive protein sources.

Procedures

General

In each of three experiments, all pigs were segregated and early weaned between 11 and 14 days of age. Pigs were housed in an 18-pen nursery with four pigs/pen. Each pen contained one nipple waterer and pigs had ad libitum access to feed and water throughout the experimental period. Heat lamps and comfort boards were provided to pigs on arrival and were removed after the treatment diets began. Continuous fluorescent lighting was provided throughout the trial. Access to the nursery was limited to individuals who had no contact with other pigs during the previous 48 hours. The nursery had its own ventilation system. Upon arrival, pigs were fed a common pelleted diet on the comfort board and in feeders from day -4 to day 0. On day 0 all pigs were weighed and randomly placed in a treatment according to weight. Pen served as the experimental unit.

Compositions of the treatment diets fed from day 0 to day 14 are shown in Table 1. All diets were formulated to contain the same amino acid ratios on an apparent digestible basis and the same lysine:metabolizable energy ratio. Diets were fed in meal form. Treatment diets were followed by two phases of common corn-soybean meal-based diets. The phase-I diet was fed from day 14 to 28 and the phase-II diet was fed from day 28 to 49 (the termination of the experiment). Pigs were weighed and feed disappearance was measured weekly to calculate average daily gain, average daily feed intake, feed conversion efficiency and feed cost per pound of gain. Feed ingredient prices used to calculate cost of gain are shown in Table 2.

Table 1. Composition of diets used in Experiments 1, 2, and 3 (as-fed basis)

Ingredient, %	Experiment 1		Experiment 2			Experiment 3		
	Complex[a]	Simple	Simple + 6% SDPP	Simple + 3% SDPP, 6%SDEP[b]	Simple + 12% SDEP	Extruded Soybean	Extruded-expelled Soybean	Soybean Meal
Corn	30.00	27.40	28.20	27.75	24.66	29.00	27.20	32.35
Spray-dried plasma protein	6.00	—	6.00	3.00	—	6.00	6.00	6.00
Spray-dried egg product	—	—	—	6.00	12.00	—	—	—
Extruded soybeans, 35% CP	—	36.00	27.00	27.00	27.00	26.25	—	—
Extruded-expelled soybeans, 42% CP	—	—	—	—	—	—	25.50	—
Soybean meal, 46.5% CP	10.00	—	—	—	—	—	—	20.50
Dried whey	27.50	27.50	27.50	27.50	27.50	27.50	27.50	27.50
Oat groats	12.50	—	—	—	—	—	—	—
Menhaden fishmeal	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Soybean oil	5.00	—	2.50	—	—	2.50	5.00	5.00
Premix[c]	4.00	4.00	3.80	3.75	3.84	3.75	3.80	3.65
Formulated composition[d]								
CP,%	20.80	22.70	23.90	24.60	25.20	24.00	24.10	23.90
Ca,%	1.03	1.06	1.04	1.05	1.06	1.04	1.04	1.04
P,%	.79	.81	.85	.84	.83	.85	.84	.84
ME, Mcal/lb	1.54	1.48	1.53	1.55	1.61	1.53	1.55	1.55
Amino acids, %								
Lysine	1.57(1.32)[e]	1.62(1.32)	1.63(1.33)	1.62(1.33)	1.68(1.39)	1.66(1.34)	1.61(1.34)	1.61(1.34)
Tryptophan	.31(.26)	.32(.26)	.34(.26)	.34(.26)	.34(.26)	.34(.27)	.33(.27)	.33(.27)
Threonine	1.09(.88)	1.09(.86)	1.13(.86)	1.13(.86)	1.15(.89)	1.18(.88)	1.17(.88)	1.13(.88)
Methionine	.42(.36)	.43(.35)	.49(.42)	.49(.42)	.51(.43)	.44(.37)	.45(.36)	.43(.36)

[a]The composition of the complex diet was the same for Exp. 1, 2, and 3.
[b]SDPP=spray-dried plasma protein and SDEP=spray-dried egg product.
[c]The premix contained crystalline amino acid additions, limestone, dicalcium phosphate, copper sulfate, vitamin and mineral premixes, and antibiotic.
[d]CP = crude protein; Ca= calcium; P = phosphorus; ME = metabolizable energy.
[e]The values in parentheses represent apparent digestible amino acid percentage in the diet.

Experiment 1

Seventy-two SEW barrows (Danbred®, USA, Inc.) were blocked by weight (initial weight = 11.7 lb) and assigned to two dietary treatments in a randomized complete block design. The two treatment diets included a "complex" diet and a "simple" diet, containing no spray dried plasma protein (SDPP, Table 1).

Experiment 2

Thirty-two SEW barrows and 32 SEW gilts [(University of Nebraska White Line x Duroc x Hampshire x Yorkshire x Danbred) x Danbred] assigned to one of four dietary treatments in a randomized complete block design. The first diet was the complex diet used in Experiment 1. The second diet (Simple + 6 percent SDPP) was the simple diet with the addition of 6 percent SDPP. The third diet was the simple diet with 3 percent SDPP and 6 percent spray-dried egg product (SDEP). The fourth diet was the simple diet with 12 percent SDEP (Table 1).

Table 2. Feed ingredient prices

Ingredient	Cost/ton, $
Corn	96
Spray-dried plasma protein	4360
Spray-dried egg protein	1300
Extruded soybeans	360
Extruded-expelled soybeans	360
Soybean meal	250
Dried whey	600
Oat groats	340
Menhaden fishmeal	760
Soybean oil	950

Experiment 3

Sixty-four SEW barrows (Danbred®, USA, Inc.) were blocked by weight (initial weight = 9.1 lb) and assigned to one of four dietary treatments in a randomized complete block design. The first diet was similar to the complex diet. The other three diets were formulated to contain the same lysine contribution from either extruded soybeans, extruded-expelled soybeans, or soybean meal (Table 1).

Results and Discussion

Experiment 1

Results from Experiment 1 are shown in Table 3. During both weeks of the treatment period, pigs fed the complex diet gained faster and consumed more feed than pigs fed the simple diet (P < .01). Average daily gain and average daily feed intake were not different for pigs during the day 0 to 49 period. While pigs consuming the complex diet were more efficient (P < .002) during the first week on treatment (P < .01), feed efficiency was not different (P > .3) during the second week of treatment. Pigs fed the complex diet gained more efficiently during the two-week treatment period (P < .02), but were not more efficient than pigs consuming the simple treatment during the day 0 to 49 period (P > .1). Feed cost per pound of gain for pigs fed the complex diet was greater (P < .0001) than that of pigs fed the simple diet during treatment week 1,

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treatment week 2, the entire treatment period and for the duration of the trial. After 49 d, no differences in pig performance could be detected between treatments, but a cost advantage still remained for the pigs fed the simple diet.

Experiment 2

Results from Experiment 2 are presented in Table 4. During the first week of treatment, pigs fed the 12 percent SDEP diet gained more slowly (P < .05) than pigs on the other three treatments. Average daily feed intake and feed efficiency of pigs on the complex diet were greater (P < .05) than that of pigs receiving the 12 percent SDEP diet during the first week of treatment. There were no differences in feed cost/per pound of gain during the first week of treatment. During the second week of treatment, there were no significant diet effects observed but the cost of gain for pigs fed diets with SDEP decreased (P < .05) compared to the complex and simple + 6 percent SDPP diet. Pigs fed the complex diet gained faster and more efficiently (P< .05) during the two week period than those fed the 12 percent SDEP diet. By the end of 49-day period, no differences among any of the treatments were detected for any performance criteria.

Experiment 3

Results of Experiment 3 are shown in Table 5. There were no differences in feed conversion during week 1 (P > .05). The cost of gain was lower (P < .05) for pigs fed the soybean meal vs complex diet. Pigs consuming the extruded-expelled soybean diet exhibited reduced (P < .05) average daily gain compared to pigs consuming either the complex or soybean meal diets. During the second week of treatment, pigs had a lower average daily gain on the extruded-expelled soybean treatment (P < .05) compared to the other three treatments. Pigs fed the soybean meal diet had reduced (P < .05) cost of gain compared to pigs fed either the complex or extruded-expelled

Table 3. Effect of diet on growth performance of pigs in Experiment 1

Item	Complex	Simple	P-value	SEM[a]
No. of pens	9	9		
Initial wt, lb	11.7	11.6	.8853	.30
Final wt, lb	75.8	73.9	.2997	1.25
Day 0-7[b]				
ADG, lb	.59	.44	.0002	.02
ADFI, lb	.77	.64	.0014	.02
ADG/ADFI	.77	.69	.0019	.03
$/lb gain	.44	.29	.0001	.03
Day 7-14				
ADG, lb	1.19	1.06	.0097	.03
ADFI, lb	1.56	1.43	.0038	.02
ADG/ADFI	.76	.74	.3223	.03
$/lb gain	.44	.27	.0001	.03
Day 0-14				
ADG, lb	.88	.75	.0006	.02
ADFI, lb	1.17	1.03	.0012	.02
ADG/ADFI	.76	.71	.0150	.02
$/lb gain	.44	.28	.0001	.02
Day 0-49				
ADG, lb	1.32	1.28	.2390	.02
ADFI, lb	2.00	1.96	.1501	.03
ADG/ADFI	.62	.61	.1231	.01
$/lb gain	.29	.24	.0001	.01

[a]Pooled standard error of the mean.
[b]ADG = average daily gain; ADFI = average daily feed intake; ADG/ADFI = feed conversion efficiency; $/lb gain = feed ingredient cost/lb of gain.

Table 4. Effect of diet on growth performance of pigs in Experiment 2

Item	Complex	Simple + 6% SDPP[a]	3% SDPP+ 6% SDEP[a]	12% SDEP[a]	SEM[b]
No. of pens	4	4	4	4	
Initial wt, lb	10.3	10.6	10.7	10.5	.08
Final wt, lb	68.8	69.9	69.8	69.0	1.56
Day 0-7[c]					
ADG, lb	.53[d]	.46[d]	.46[d]	.35[e]	.01
ADFI, lb	.73[d]	.68[de]	.66[de]	.59[e]	.01
ADG/ADFI	.73[d]	.68[de]	.68[de]	.58[e]	.03
$/lb gain	.45	.47	.42	.44	.04
Day 7-14					
ADG, lb	.79	.77	.73	.79	.01
ADFI, lb	1.10	1.10	1.08	1.17	.01
ADG/ADFI	.72	.69	.68	.67	.01
$/lb gain	.46[d]	.47[d]	.41[e]	.38[e]	.02
Day 0-14					
ADG, lb	.66[d]	.62[de]	.59[e]	.57[e]	.01
ADFI, lb	.90	.90	.88	.88	.01
ADG/ADFI	.72[d]	.69[de]	.68[de]	.63[e]	.01
$/lb gain	.46[de]	.47[d]	.42[de]	.41[e]	.03
Day 0-49					
ADG, lb	1.19	1.21	1.21	1.19	.02
ADFI, lb	2.05	2.05	2.07	2.05	.02
ADG/ADFI	.57	.59	.59	.59	.01
$/lb gain	.28	.28	.26	.26	.01

[a]SDPP= Spray-dried plasma protein, SDEP = spray-dried egg protein.
[b]Pooled standard error of the mean.
[c]ADG = average daily gain; ADFI = average daily feed intake; ADG/ADFI = feed conversion efficiency; $/lb gain = feed ingredient cost/lb of gain.
[de]Means in the same row without a common superscript are different (P < .05).

Table 5. Effect of diet on growth performance of pigs in Experiment 3

Item	Complex	Extruded Soybean	Extruded-Expelled Soybean	SBM[a]	SEM[b]
No. of pens	4	4	4	4	
Initial wt, lb	9.1	9.2	9.1	9.1	.06
Final wt, lb	67.3	65.7	63.7	67.5	.92
Day 0-7[c]					
ADG, lb	.66[d]	.59[de]	.48[e]	.66[d]	.01
ADFI, lb	.81[d]	.73[de]	.59[e]	.75[de]	.02
ADG/ADFI	.80	.80	.85	.89	.02
$/lb gain	.42[d]	.36[de]	.36[de]	.32[e]	.04
Day 7-14					
ADG, lb	.84[d]	.79[d]	.64[e]	.81[d]	.01
ADFI, lb	1.25[de]	1.30[d]	1.17[de]	1.16[e]	.01
ADG/ADFI	.66[de]	.60[de]	.56[e]	.70[d]	.02
$/lb gain	.50[d]	.48[de]	.53[d]	.42[e]	.04
Day 0-14					
ADG, lb	.75[d]	.68[d]	.57[e]	.73[d]	.01
ADFI, lb	1.03[d]	1.01[de]	.88[e]	.95[de]	.01
ADG/ADFI	.71[de]	.67[de]	.65[e]	.77[d]	.02
$/lb gain	.46[d]	.42[de]	.45[d]	.37[e]	.03
Day 0-49					
ADG, lb	1.19	1.14	1.12	1.17	.01
ADFI, lb	1.87	1.85	1.74	1.83	.03
ADG/ADFI	.64	.62	.65	.64	.01
$/lb gain	.27[d]	.27[de]	.26[de]	.25[e]	.01

[a]Soybean meal, 46.5% crude protein.
[b]Pooled standard error of the mean.
[c]ADG = average daily gain; ADFI = average daily feed intake; ADG/ADFI = feed conversion efficiency; $/lb gain = feed ingredient cost/lb of gain.
[de]Means in the same row with different superscripts differ (P < .05).

diet. Average daily gain was less for pigs fed the extruded-expelled diet than for pigs fed the other three treatments from day 0 to 14 (P < .05). Pigs fed the extruded-expelled soybean diet had decreased average daily gain and increased cost of gain when compared to pigs fed the soybean meal diet. No differences could be detected among treatments for any of the growth performance criteria for the entire 49-d period. Pigs fed the soybean meal diet had a lower (P < .05) cost of gain compared to pigs fed the complex diet for the 49-d trial period.

Conclusion

The performance of the SEW pigs used in this study was excellent, reflecting the source of pigs used are characterized to have a superior lean-gain/growth potential. Growth performance data suggest SEW pigs can efficiently utilize egg and soybean-based protein sources during the immediate postweaning period. Further refinement of the potential of these protein sources will help provide an economical alternative to conventional protein sources used in SEW diets.

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Dietary Fiber in Sow Gestation Diets — An Economic Analysis

Duane E. Reese[1]

Summary and Implications

A previous research summary indicated sows fed high-fiber diets during gestation weaned an average of .3 more pigs/litter than sows fed lower-fiber, grain-based diets. Gestation diets containing 45 percent wheat midds, 20 percent soybean hulls, 25 percent alfalfa meal, 30 percent sugar beet pulp or 40 percent oats provide similar amounts of neutral detergent fiber (NDF), which should be sufficient to increase litter size weaned by .3 pigs per litter. An economic analysis suggests feeding a diet containing these sources of NDF would increase sow feed ingredient costs from 0 to $3.30/sow/period (110 days) compared to feeding a corn-soybean meal-based diet. However, income generated from the additional pigs weaned/litter would, more than likely, offset as much as a $6 increase in sow feed ingredient cost that could be associated with feeding sows high-fiber diets during gestation. Producers may be able to improve their operation's profitability and perhaps sow welfare by using fibrous feed ingredients in sow gestation diets.

Introduction

Gestating sows are well-suited to utilize high-fiber, low energy-dense diets. They utilize fiber better than growing pigs and they have a high feed intake capacity relative to their gestational energy requirement. Results from a review of 24 research studies on the effects of providing high-fiber diets to sows during gestation appeared in the 1997 Nebraska Swine Report. The most significant finding in that review: sows fed high-fiber diets during gestation weaned .3 more pigs/litter on the average than did sows fed low-fiber, con-

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trol diets. The most recent study included in that review showed feeding wheat straw during gestation resulted in .7 more pigs weaned per litter. It seems sows should consume 350 to 400 grams/day of neutral detergent fiber (NDF) during gestation to increase the number of pigs weaned/litter.

There may be situations which justify using fibrous feed ingredients in sow gestation diets. When making a decision to add fiber to gestation diets, it is important to conduct an economic analysis. The economic analysis presented in this paper does not include costs associated with ingredient storage, feed handling and manure disposal.

Procedures

Six gestation diets were formulated (Table 1). One diet was corn-soybean meal-based and the others contained either 45 percent wheat midds, 20 percent soybean hulls, 25 percent alfalfa meal, 30 percent sugar beet pulp or 40 percent oats. All diets were designed to provide sows with similar daily amounts of metabolizable energy, lysine, calcium and available phosphorus by altering ingredient composition and daily feed intake. The metabolizable energy values used for wheat midds, soybean hulls, alfalfa meal and beet pulp were obtained from research trials where sows were used as the experimental animal. Each of the high-fiber diets were formulated to provide about 350 grams/day of NDF when fed at 6.1 Mcal of metabolizable energy per sow per day. Total sow feed ingredient cost and the total amount of feed to be consumed were estimated for each diet. A standard feeding period of 110 days was assumed.

Table 1. Diets for gestation sows

Ingredient	Diet: Corn-soy	45% Wheat midds	20% Soybean hulls	25% Alfalfa meal	30% Beet pulp	40% Oats
Corn	1689	933	1352	1339	1194	943
Soybean meal, 46.5% CP	220	85	165	95	131	173
Wheat midds		900				
Soybean hulls			400			
Alfalfa meal				500		
Beet pulp					600	
Oats						800
Dicalcium phosphate, 18.5% P	55	35	52	43	51	48
Limestone	13	24	8		1	13
Salt	10	10	10	10	10	10
Vitamin/trace mineral mix	13	13	13	13	13	13
Daily intake						
Feed, lb	4.1	4.4	4.4	4.6	4.6	4.5
Metabolizable energy, Mcal[a]	6.1	6.1	6.1	6.1	6.1	6.1
Lysine, g	10.3	11.0	11.0	11.0	11.0	11.1
Calcium, g	16.9	18.5	17.2	17.8	16.6	17.2
Phosphorus, g	15.0	17.4	15.0	14.2	14.5	15.5
Phosphorus (available), g	10.4	10.5	10.5	10.4	10.5	10.6
Neutral detergent fiber, g	140	355	350	375	355	344
Calculated analysis						
Lysine, %	.55	.55	.55	.53	.53	.54
Calcium, %	.90	.93	.86	.86	.80	.85
Phosphorus, %	.80	.87	.75	.66	.70	.76

[a]Metabolizable energy values (Mcal/lb) for corn, soybean meal, wheat midds, soybean hulls, alfalfa meal, beet pulp, and oats were 1.55, 1.54, 1.35, 1.07, .9, 1.05, and 1.24, respectively.

Table 2. Feed ingredient costs and feed usage estimates for various gestation feeding programs

Item	Diet: Corn-soy	Wheat midds	Soybean hulls	Alfalfa meal	Beet pulp	Oats
Feed cost/ton, $[a]	122.00	116.00	118.00	124.00	122.00	112.00
Feed cost/sow/period, $[a,b]	27.61	27.94	28.27	30.91	30.36	27.61
Gestation feed usage, lb/sow/period[b]	450	485	485	505	505	495

[a] Ingredient prices used were corn $2.50/bu; soybean meal $225/ton; wheat midds $102/ton; soybean hulls $88/ton; alfalfa meal $135/ton; beet pulp $110/ton; oats $1.40/bu; dicalcium phosphate $275/ton; and limestone $100/ton.
[b]Period = 110 days; Daily metabolizable energy intake = 6.1 Mcal.

Table 3. Increase in number of pigs weaned/litter to offset extra sow feed ingredient expense

Extra sow feed expense, $/sow/period[a]	Value of a pig at weaning, $/pig: 20	25	30	35	40
2	.11	.09	.07	.06	.06
4	.23	.18	.15	.13	.11
6	.34	.27	.23	.19	.17

[a]Period = 110 days.

Results and Conclusions

As expected, there was cost variation of the complete diets ($/ton) and in the total sow feed ingredient expense ($/sow/110-day period) among the six feeding programs (Table 2). The total feed cost per-sow per-period for the diets with various sources of additional fiber was up to $3.30/sow higher than that for the corn-soybean meal diet. The cost of feeding the 40 percent oat diet was the same as for the corn-soybean meal-based diet. Expense incurred from feeding the 45 percent wheat midds or 20 percent soybean hulls diet was slightly higher ($.33 and .66/sow, respectively) than that for the corn-soybean meal diet. The 25 percent alfalfa meal and 30 percent beet pulp feeding programs were $3.30 and 2.75/sow more expensive than the corn-soybean meal-based program.

When lower energy, fibrous feedstuffs are added to the diet, sows must be provided more feed to meet their daily metabolizable energy requirement (estimated at 6.1 Mcal of metabolizable energy per day for this analysis). Feeding a gestation diet containing 45 percent wheat midds or 20 percent soybean hulls will result in a 8 percent increase in feed usage compared to feeding a corn-soybean meal diet (Table 2). Feeding a diet with 25 percent alfalfa meal, 30 percent beet pulp or 40 percent oats will increase feed usage by 12, 12 and 10 percent compared to feeding a corn-soybean diet. Therefore, it is important to compare total feed ingredient cost/sow/period rather than ingredient cost/ton of feed when evaluating the economics of feeding high-fiber diets to gestating sows.

The amount of manure solids produced from feeding these high-fiber diets would probably proportionally increase as well which could be a problem in some manure disposal systems. Some producers report the undigested portion of the hull from oats is particularly a nuisance to remove from manure storage devices.

In Table 3 the increase in litter size at weaning needed to offset a range of additional feed ingredient expenses is presented. The calculations are based on pig values at weaning of $20, 25, 30, 35 and 40/pig. These results indicate a relatively small improvement in the number of pigs weaned/litter is necessary to offset even a $6 increase in sow feed ingredient cost/110-day period.

Based on the results of the original review presented in the 1997 Nebraska Swine Report, the probability of an increase in litter size weaned of the magnitudes shown in Table 3 is high. Of the 24 studies evaluated in the original review, eight showed a sow response to feeding fiber that was either negative (sows fed high-fiber diets weaned fewer pigs than those fed a control diet) or zero. The litters in these eight studies represented only 19 percent of all the litters evaluated in the original review. Of the remaining 16 studies, there was an increase in litter size that ranged from .1 to 1.2 pigs/litter.

Feeding fiber to gestating sows also reduces the incidence of stereotypic behavior, such as bar-biting, floor licking or sham-chewing. The presence of fiber in the diet seems to result in a more "satisfied" sow. The same situation has been observed in breeding boars. The financial and production consequences of having more satisfied or docile breeding animals have not been examined.

Diets containing fibrous feedstuffs will have a lower bulk density (lb/ft^3) than simple grain-soybean meal-based diets. Therefore, it is necessary to increase not only the weight but also the volume of feed offered for the sow to consume a sufficient amount of nutrients. Producers who use automated feed delivery systems with "feed boxes" must adjust the box settings when a high-fiber diet is used. Otherwise, sows will not be able to consume enough energy and other nutrients to gain an adequate amount of weight and condition during gestation. In some cases, it will not be possible to feed the high-fiber diets in shown in Table 1 once daily through feed delivery systems with "feed boxes," because the boxes are too small. In that case, divide the sows' daily allotment into two daily feedings. In feeding systems where scoops and buckets are used to handle feed, a greater volume of feed is also required. In addition, pelleting high-fiber ingredients and diets facilitates easier handling, including removal from bulk bins.

Wheat midds may be contaminated with vomitoxin, a mycotoxin that causes reduced feed intake in pigs. When feeding a diet containing 900 pounds of wheat midds/ton, such as the one shown in Table 1, it is important to have an excellent quality control program to monitor for possible vomitoxin contamination in the midds. Otherwise, consider including 400 to 450 pounds of wheat midds/ton of feed to minimize the impact of any vomitoxin contamination that may be undetected.

The high fiber diets in Table 1 are designed to provide sows with about 350 grams/day of NDF, which is about 210 grams more than that provided by a corn-soybean meal-based diet. It is important to note that definitive research results are not available to adequately describe the relationship between each gram of additional NDF consumed by the sow and possible changes in reproductive performance. Thus, sows may not need to consume 350 to 400 grams/day of NDF to wean an extra .3 pigs/litter. A recent cooperative study completed at several American universities indicated that when sows consumed a diet providing them with 368 grams/day of NDF, they weaned .7 more pigs/litter than did those fed about 140 grams/day of NDF from corn-soybean meal. Thus, if practical problems preclude the preparation, handling and feeding of the high-fiber diets in Table 1, consider reformulating the diets to provide sows with about 100 grams/day of additional NDF (total of 240 to 250 grams/day of NDF). In that case, diets would contain about 23 percent wheat midds, 10 percent soybean hulls, 12 percent alfalfa meal, 15 percent sugar beet pulp, or 20 percent oats.

The diets shown Table 1 are made using a vitamin and trace mineral premix which provides maximum flexibility for adding fibrous feedstuffs to the diet. A supplement or base mix designed for use with grain and soybean meal should not be used with any fibrous ingredient without first checking with the manufacturer of the product or a nutritionist. The nutrients found in many fibrous feedstuffs vary considerably in amount and digestibility from those found in grain and soybean meal. These differences should be considered in diet formulation.

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Plasma Urea Can Be Used To Identify The Protein Requirements of Group-penned Finishing (130 to 220 lb) Barrows and Gilts Fed Corn-soybean Diets

Phillip S. Miller
Austin J. Lewis
Hsin-Yi Chen

Summary and Implications

In this study, growth performance data from finishing pigs indicate the response of barrows and gilts to dietary protein concentration was maximized with a 15 percent protein corn-soybean meal diet. Review of the response of plasma urea concentration to dietary protein intake indicated that, in this study, the protein requirement of barrows was between 12 and 15 percent and the protein requirement for gilts was between 15 and 18 percent. Based on the many findings in the literature documenting that protein requirements (percent of the diet) of gilts are greater than those of barrows, we believe the use of plasma urea is an alternative approach to using growth performance data for establishing the protein (amino acid) requirements of finishing pigs. Identifying a small number of pigs for blood sampling may provide a less intensive method to help gain insight into the protein requirements of barrows and gilts during the finishing period. Future research will focus on refining the plasma urea technique to identify the response of barrows and gilts to dietary protein. Specifically, we are interested in pursuing the application of this methodology to commercial conditions.

Introduction

In the 1995 University of Nebraska Swine Report (pg. 42) we described a method to help determine the protein requirements of pigs with different genetic potentials for lean growth. We observed the response of plasma urea during the growing-finishing period was sensitive to changes in protein intake of pigs consuming corn-soybean meal diets. However, pigs used in the above experiment were housed individually and the two groups exhibited significantly different growth rates (a good research model, but limited applicability to the swine industry).

Therefore, the objective of the present study was to determine whether the profile of plasma urea concentration during the finishing period could be used to determine the response of group-penned finishing barrows and gilts to dietary protein concentration.

Procedures

One hundred twenty barrows and 120 gilts were used in a randomized complete-block experiment designed to investigate the use of plasma urea concentration as a method to identify protein requirements of group-penned finishing pigs. Pigs used in the experiment were considered to have a medium- to high-lean gain potential ((University of Nebraska White line x Duroc × Hampshire × Yorkshire × Danbred) × Danbred). Treatments were arranged in a 2× 4 factorial (two sexes and four diets). Each sex × diet combination was replicated three times.

Barrows and gilts (initial BW = 135 lb) were penned separately and each pen contained 10 pigs (5 ft^2/pig). Pigs were housed in a modified open-front building at the Swine Research Facility near Mead, NE. The duration of the experiment was 56 days and was

Table 1. Ingredient and analyzed composition of diets, as-fed basis

	Dietary protein concentration, %			
Ingredient, %	9	12	15	18
Corn	94.50	87.40	79.8	72.00
Soybean meal, 46.5% CP	2.75	10.00	17.75	25.70
Dicalcium phosphate	1.30	1.10	.90	.75
Limestone	.35	.40	.45	.45
Salt	.30	.30	.30	.30
Mineral premix	.10	.10	.10	.10
Vitamin premix	.70	.70	.70	.70
Analyzed composition, %				
Crude protein	9.31	12.31	14.86	17.94
Lysine	.29	.51	.64	.82
Calcium	.64	.64	.65	.64
Phosphorus	.51	.52	.53	.51

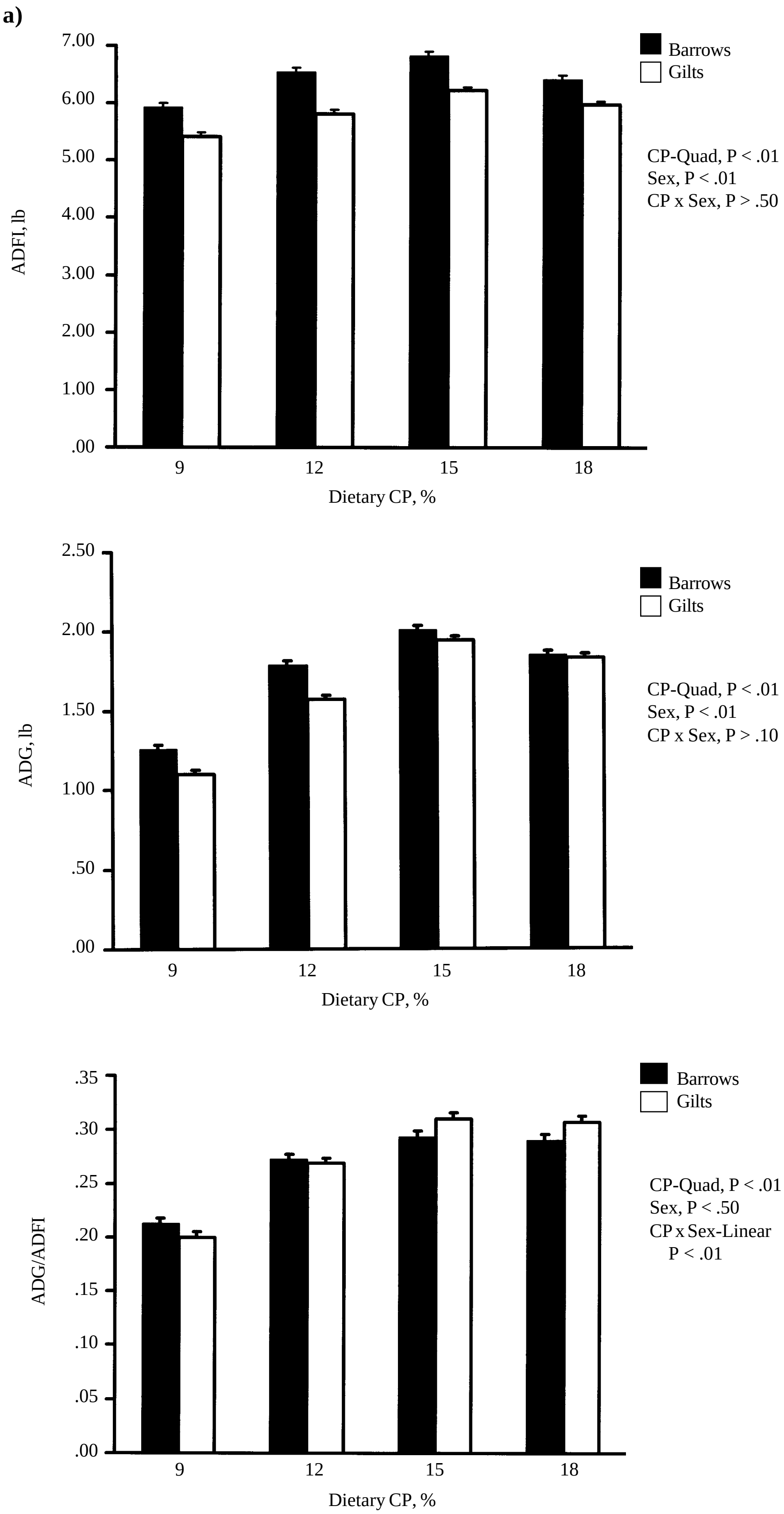

Figure 1. The response of a) average daily feed intake (ADFI), b) average daily gain (ADG), and c) feed efficiency (ADG/ADFI) to dietary protein concentration for barrows and gilts during the finishing period.

initiated in early August, 1996. Four corn-soybean meal-based diets formulated to contain 9, 12, 15 or 18 percent dietary protein (Table 1) were used. Each pen received the respective diet for the entire experiment. Pigs were weighed, feed disappearance determined and blood samples taken every seven days. Plasma was harvested and frozen until analyzed for urea content.

Growth performance data were analyzed as a randomized complete-block design with sex and dietary protein concentration as main effects. Orthogonal contrasts were developed to examine the pattern of growth performance responses to sex, protein concentration and the sex × protein concentration interaction.

Results and Discussion

Feed intake responded quadratically (P < .01) to dietary protein concentration (Figure 1a). Also, barrows consumed approximately 10 to 16 percent more (P < .01) feed than gilts. For both barrows and gilts, average daily feed intake was maximized in pigs consuming the 15 percent protein diet. The response of average daily gain to protein concentration (Figure 1b) was similar to that for average daily feed intake. Growth rate responded quadratically (P < .01) to dietary protein concentration and barrows consistently exhibited greater (P < .01) average daily gain than gilts. Again, the response of average daily gain was maximized in pigs consuming the 15 percent protein diet. Although feed efficiency responded quadratically (P < .01) to dietary protein concentration (Figure 1c, maximized in both barrows and gilts at 15 percent protein), no differences (P > .50) between barrows and gilts were observed. A protein concentration × sex interaction (P < .01) was observed for feed efficiency and can be attributed to the greater feed efficiencies for barrows compared to gilts below 15 percent protein and greater feed efficiencies for gilts compared to barrows at or above 15 percent dietary protein.

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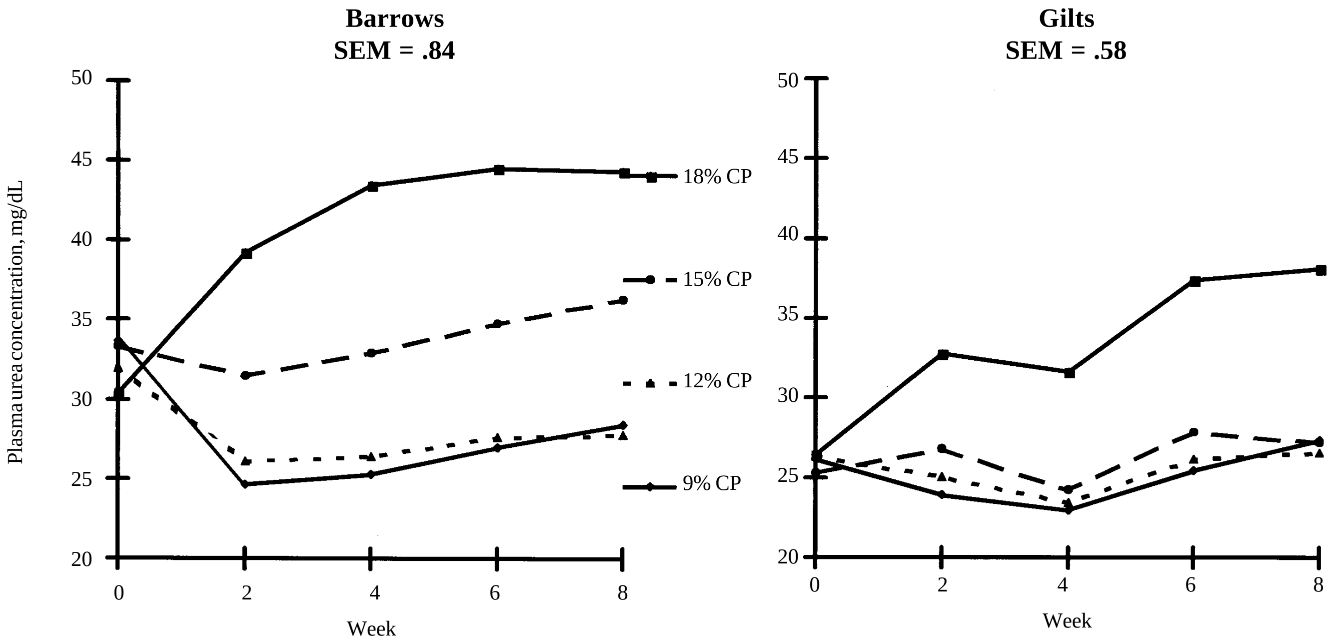

Figure 2. The response of plasma urea to dietary protein concentration for barrows and gilts during the 56-day finishing period.

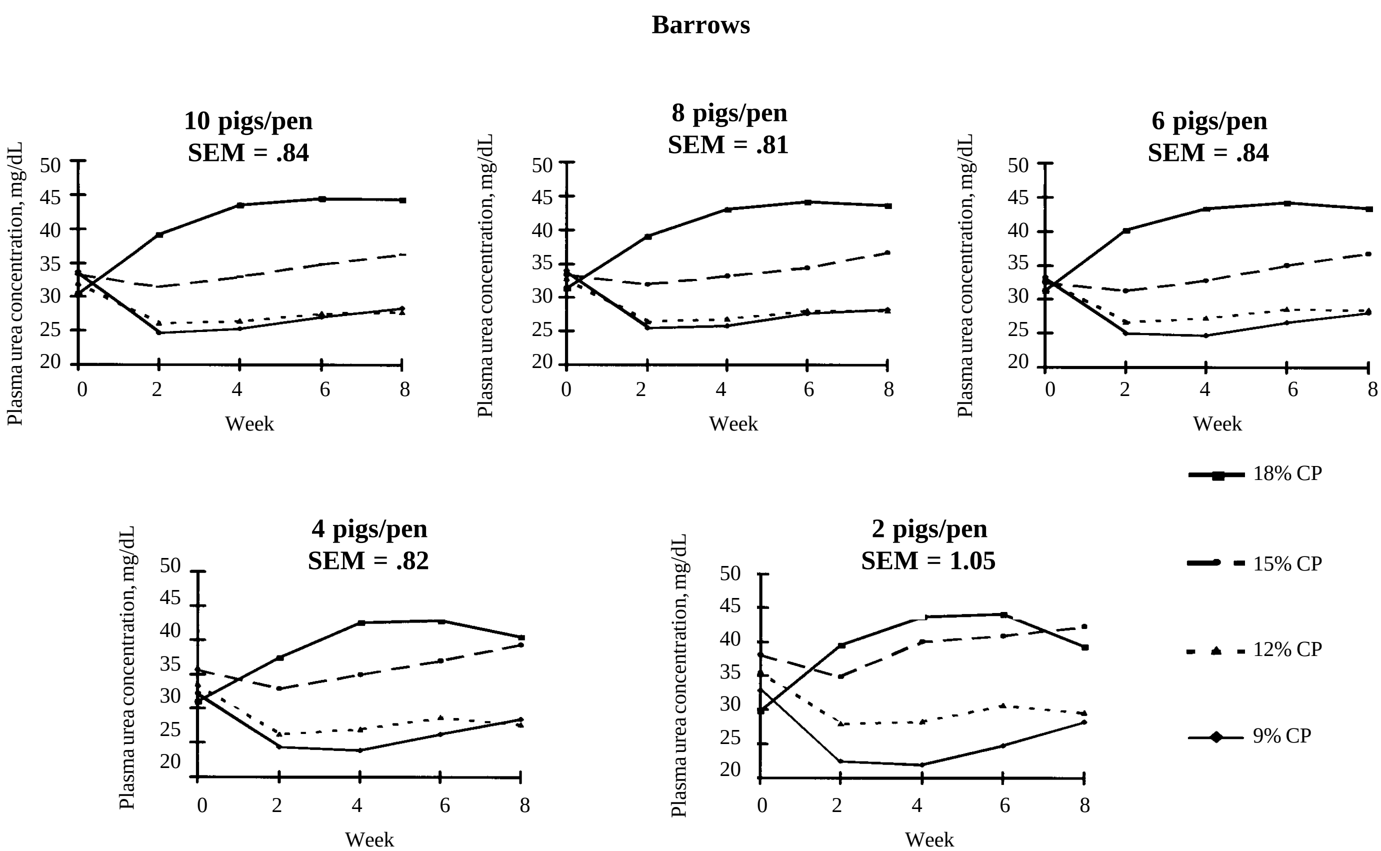

Figure 3. The response of plasma urea concentration to dietary protein concentration for barrows from data sets containing either 2, 4, 6, 8, or 10 pigs/ pen.

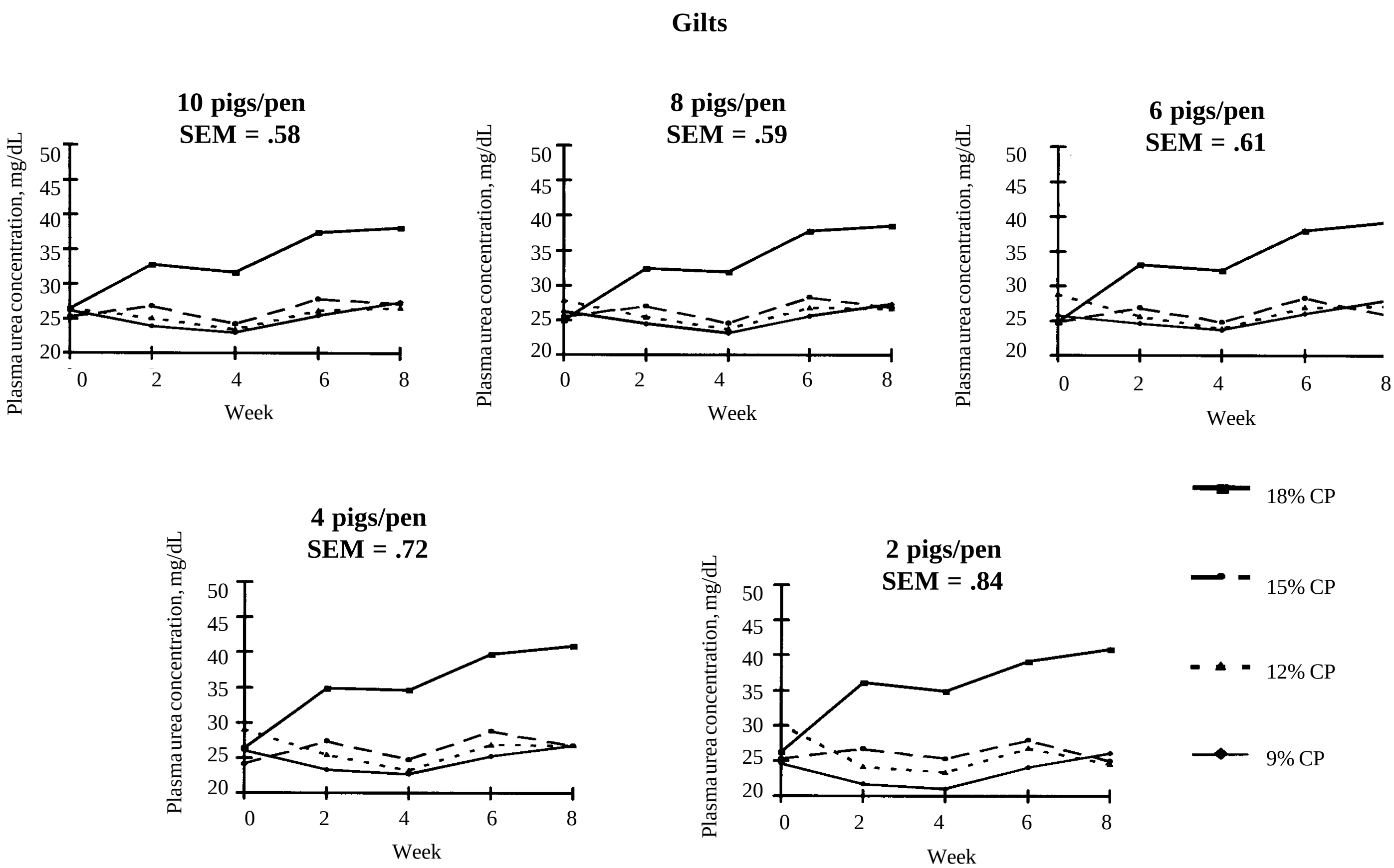

Figure 4. The response of plasma urea concentration to dietary protein concentration for gilts from data sets containing either 2, 4, 6, 8, or 10 pigs/pen.

Based on growth performance data, we determined the maximum response to dietary protein concentration to be 15 percent. Although barrows ate more feed and grew faster than gilts, these growth performance data do not indicate different protein requirements (percent of the diet) for barrows and gilts. Because of the relatively wide differences between protein levels, we may have been unable to determine the requirements if the differences between barrows and gilts had been one to two percent dietary protein.

The responses of plasma urea to dietary protein concentration during the 56-day experiment are presented in Figures 2, 3 and 4. An assumption we used to evaluate these plasma urea profiles: a minimum plasma urea concentration will be exhibited until the dietary protein requirement is achieved. Excess protein intake above the requirement will result in more urea (nitrogen) excretion and an increase in plasma urea concentration. Based on this model, Figure 2 suggests the threshold for dietary protein concentration for barrows was between 12 and 15 percent protein and that is was between 15 and 18 percent protein for gilts. Interestingly, the threshold plasma urea concentration was similar (~ 25 mg/dL) for barrows and gilts.

Because it would be desirable to take blood from just a few pigs rather than all the pigs in the pen (10 pigs in the present experiment) when acquiring blood samples for plasma urea analysis, we randomly selected data sets containing eight, six, four or two pigs/pen to see how many pigs are needed to accurately define the relationship between plasma urea concentration and dietary protein concentration (see Figures 3 and 4). For the barrows, the profile of the plasma urea response to dietary protein concentration was maintained with as few as six pigs/pen (Figure 3). For gilts, four pigs/pen was adequate (Figure 4). These results indicate that it may be best to pick pigs from large pens instead of selecting all pigs for blood sampling. Future studies will focus on using plasma urea profiles to examine the response of pigs to dietary protein intake. We believe that, with proper care, this technique is an excellent alternative to using growth performance data to assess the response of pigs to dietary protein concentration.

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Responses of Barrows Consuming a Diet Formulated on an Ideal Protein Basis at Different Feeding Levels

Sergio Gomez
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Hsin-Yi Chen[1]

Summary and Implications

An experiment was carried out to evaluate the performance, nutrient digestibilities and plasma metabolites of barrows fed with a corn-soybean meal diet (CONTROL) or a diet formulated on an ideal protein basis (IDEAL; supplemented with crystalline lysine, threonine, tryptophan and methionine). Each diet was offered either on an ad libitum basis or at a feeding level of 90 or 80 percent of ad libitum feed intake. Averaged for the entire experimental period, barrows fed the CONTROL diet gained seven percent faster ($P < .05$) and were five percent more efficient ($P < .01$) than barrows fed the IDEAL diet. As the level of feed intake decreased, there was a decrease in daily gain ($P < .01$), but feed efficiency tended to be improved ($P < .10$) for barrows fed 90 percent of ad libitum. The apparent digestibilities of dry matter and energy were approximately three percent greater ($P < .01$) for barrows fed the IDEAL diet. Plasma urea concentrations were lower in barrows fed the IDEAL diet, regardless of feeding level; however, for barrows fed the CONTROL diet, the urea concentration was lower when the feeding level was 80 percent of ad libitum (diet x level, $P < .01$). Over time, the urea concentration declined in barrows fed the IDEAL diet (diet x time, $P < .01$). The concentrations of plasma glucose were lower in barrows fed the CONTROL diet ($P < .01$), were reduced with each reduction in the feeding level ($P < .01$), and were diminished over time throughout the experiment ($P < .01$). Plasma nonesterified fatty acid concentrations were lower in barrows fed the CONTROL diet at the beginning of Phase 2 (diet x time, $P < .05$). The reduction in daily gain observed with the IDEAL diet suggests a deficiency of other essential amino acid(s) may have limited the growth potential of these pigs or that the "ideal" pattern was not correct for the pigs used in this research. Results from this study will help to provide a basis for future studies to investigate the apparent reduction in performance sometimes observed in pigs consuming lower protein, amino acid-supplemented diets. We recognize the reduction in growth performance observed for the IDEAL diet may be offset by changes in body composition.

Introduction

In the 1996 Nebraska Swine Report, the concept and application of ideal protein was introduced. In that report, it was found the performance of gilts fed a corn-soybean meal diet was similar to that of gilts consuming a diet formulated on an ideal protein basis (first four limiting amino acids). However, it was also reported that barrows fed a corn-soybean meal diet had better performance than barrows fed the diet formulated on an ideal protein basis. The 1997 Nebraska Swine Report described another experiment with ideal protein. In the 1997 research, the use of the ideal protein diet resulted in a reduction in aerial ammonia concentration.

An ideal amino acid pattern allowing optimal growth performance is essential to serve as a method to reduce nitrogen excretion from pig production units and to use patterns of amino acids in more precise ways to establish nutrient requirements. The present experiment was conducted to identify possible mechanisms responsible for the reduced productivity of barrows consuming a corn-soybean meal-amino acid supplemented diet. In addition, the effect of feed intake reductions (to simulate feed intake under commercial conditions) on the efficiency of diet utilization was also evaluated.

Procedures

Thirty-six crossbred barrows (Danbred®, USA, Inc.; Dorchester, NE) with an initial weight of 69 pounds were allotted to a randomized complete block experiment with a factorial arrangement of six treatments. Two dietary treatments were combined with three different levels of feed intake.

Table 1. Diet composition (as-fed basis)

Item, % Diet	Phase 1[a]		Phase 2[a]	
	CONTROL[b]	IDEAL[b]	CONTROL	IDEAL
Corn	74.34	84.51	79.80	89.93
Soybean meal, 46.5% CP	20.96	10.13	15.45	4.71
Tallow	2.00	2.00	2.00	2.00
Dicalcium phosphate	1.20	1.40	1.25	1.50
Limestome	.40	.40	.40	.34
Salt	.30	.30	.30	.30
Vitamin mix	.70	.70	.70	.70
Trace mineral mix	.10	.10	.10	.10
L-lysine HCl	—	.33	—	.33
L-threonine	—	.08	—	.06
DL-methionine	—	.04	—	.01
L-tryptophan	—	.01	—	.02
Chemical composition				
Crude protein, %[c]	16.21	13.04	14.22	10.21
Lysine, %[d]	.82	.78	.67	.63
Calcium, %[d]	.67	.68	.66	.66
Phosphorus, %[d]	.56	.55	.55	.54
Gross energy, Mcal/lb[c]	1.82	1.79	1.80	1.80

[a]Phase 1 = 69 to 118 lb body weight; phase 2 = 118 to 181 lb body weight.
[b]CONTROL= corn-soybean meal diet; IDEAL= corn-soybean meal-amino acid supplemented diet.
[c]Analyzed.
[d]Calculated.

Table 2. Total and true ileal digestible amino acid composition of the diets (as-fed basis)

Item, % Diet	Phase 1[a]		Phase 2[a]	
	CONTROL[b]	IDEAL[b]	CONTROL	IDEAL
Lysine	.82(.69)[c]	.78(.69)	.67(.56)	.63(.56)
Tryptophan	.20(.17)	.15(.13)	.17(.15)	.13(.11)
Threonine	.62(.52)	.56(.48)	.55(.46)	.47(.39)
Methionine + cysteine	.54(.48)	.50(.45)	.50(.44)	.43(.37)

[a]Phase 1 = 69 to 118 lb body weight; phase 2 = 118 to 181 lb body weight.
[b]CONTROL= corn-soybean meal diet; IDEAL= corn-soybean meal-amino acid supplemented diet.
[c]Values in parentheses represent calculated true ileal digestible percentages.

The diets used in the experiment are presented in Table 1. Phase 1 diets were offered for 25 days, until pig weight was approximately 118 lb. Phase 2 diets were provided for the next 30 days, until pig weight was approximately 181 lb. In each phase, a corn-soybean meal (CONTROL) or a corn-soybean meal-amino acid supplemented (IDEAL) diet was fed. Eighteen pigs received each dietary treatment. Three subgroups of six pigs were formed within each dietary treatment and allotted to one of three feeding levels: 1) pigs had ad libitum access to their diet, 2) pigs were offered 90 percent or 3) pigs were offered 80 percent of the feed consumed by the pigs with ad libitum access to the diet. Pigs with ad libitum access to their diet had feed available continuously. Feeders from pigs in this group were weighed daily to calculate the feed to be offered to pigs allotted to the other two feeding levels for the next 24 hours.

In the IDEAL diets, the protein concentration was reduced approximately four percent from the CONTROL diet (16.2 to 13.0 percent, phase 1; 14.2 to 10.2 percent, phase 2). The four first limiting amino acids (lysine, threonine, methionine and tryptophan) were added as crystalline amino acids to the IDEAL diet to meet the lysine concentration of the CONTROL diet and provide an amino acid pattern (relative to lysine) similar to the ideal pattern developed at the University of Illinois. The concentration of lysine and the ratios used for the next three limiting amino acids were based on calculated true ileal digestible values (Table 2). In order to meet the objectives of the study, the CONTROL and IDEAL diets were formulated to be slightly below the requirements for lysine and other amino acids.

All pigs were individually penned in an environmentally controlled room. Pigs remained on the study for 55 days. Pigs had ad libitum access to water and were fed three times a day throughout the experiment (9:00, 13:00 and 17:00 hours). Pigs were weighed and blood samples were taken weekly. Plasma samples were analyzed for urea, glucose and nonesterified fatty acids (NEFA). The response of each of these metabolites versus week of the study was examined. During the third week of phase 2, .25 percent of chromic oxide (Cr_2O_3) was added to the diet as an indigestible marker. Fecal samples were collected from each barrow during three consecutive days to calculate the apparent digestibility of dry matter, crude protein and energy.

Results and Discussion

The performance of barrows consuming the CONTROL and the IDEAL diets for phase 1, phase 2, and the overall period is presented in Table 3. During phase 1, the daily gain ($P < .05$) and the feed efficiency ($P < .01$) were six percent greater for pigs fed the CONTROL diet compared with pigs fed with the IDEAL diet. As the level of feed intake decreased there was a concomitant decrease in daily gain ($P < .01$). During phase 2, pigs fed the CONTROL diet gained eight percent more weight ($P < .05$) and consumed five percent more feed ($P < .10$) than pigs fed the IDEAL diet. As the level of feed intake was reduced from ad libitum to a 80 percent of ad libitum, there was a reduction in daily gain ($P < .01$), however feed efficiency was greater ($P < .05$) for pigs fed 90 and 80 percent of ad libitum. Averaged for the entire experimental period, pigs

(Continued on next page)

fed the CONTROL diet gained seven percent faster (P < .05) and were five percent more efficient (P < .01) than pigs fed the IDEAL diet. Similarly, as the level of feed intake decreased, there was a decrease in daily gain (P < .01), but feed efficiency tended to be greater (P < .10) for pigs fed 90 percent of ad libitum. Overall, these findings agree with previous results in which barrows fed a corn-soybean meal diet had better performance than barrows fed an ideal protein diet similar to the one used in this experiment. The reduction in daily gain observed for pigs fed the IDEAL diet may suggest either a deficiency in other essential amino acid(s) that may have limited the growth potential of these pigs, or that the “ideal” pattern is not ideal for the pigs used in this study.

The apparent digestibilities of dry matter and energy were approximately three percent greater (P < .01) in pigs fed the IDEAL diet; however, the improved efficiency of nutrient digestion was not reflected in the performance of pigs fed the IDEAL diet. The greater digestibility may have been because fecal samples were collected during phase 2, during which feed intake of pigs fed the CONTROL diet was about five percent greater than that of pigs fed the IDEAL diet. Generally, there is an inverse relationship between feed intake and digestibility.

Plasma urea, glucose and NEFA concentrations are presented in Figures 1, 2 and 3, respectively. Plasma urea concentrations were lower for pigs fed the IDEAL diet than for pigs fed the CONTROL diet, regardless of feeding level. Furthermore, for pigs fed the CONTROL diet, the urea concentration was lower for pigs fed with a feeding level of 80 percent, compared with pigs fed on an ad libitum basis or with a feeding level of 90 percent (diet x level, P < .01). Over time, the plasma urea concentrations changed little in pigs fed the CONTROL diet, whereas the urea concentration declined in pigs fed the IDEAL diet (diet x time, P < .01). An excess plasma urea concentration may be expected when dietary protein is increased or when a diet with a disproportion in the amino acid con-

Table 3. Performance of barrows fed control corn-soybean meal and ideal protein diets at three different feeding levels

	Diet	CONTROL[b]			IDEAL[b]			
Item[a]	Level, %	100	90	80	100	90	80	SEM[c]
No. of pigs		6	6	6	6	6	6	
Phase 1								
Initial wt., lb		69.24	69.16	70.12	69.13	69.09	68.94	0.756
Final wt, lb[de]		126.62	120.04	113.73	121.66	116.26	111.53	1.702
ADG, lb[de]		2.30	2.04	1.74	2.10	1.89	1.70	.061
ADFI, lb[e]		4.71	4.17	3.76	4.64	4.18	3.74	.111
ADG/ADFI[f]		.49	.49	.46	.45	.45	.45	.010
Phase 2								
Final wt., lb[de]		197.32	187.15	172.47	186.27	176.80	167.44	4.172
ADG, lb[de]		2.36	2.24	1.96	2.15	2.02	1.86	0.097
ADFI, lb[eh]		6.49	5.66	5.13	6.12	5.44	4.88	0.192
ADG/ADFI[g]		.36	.40	.38	.35	.37	.38	0.009
Overall								
ADG, lb[de]		2.33	2.15	1.86	2.13	1.96	1.79	0.071
ADFI, lb[e]		5.70	5.00	4.52	5.47	4.88	4.38	0.151
ADG/ADFI[fi]		.41	.43	.41	.39	.40	.41	0.007

[a]ADG=average daily gain, ADFI= average daily feed intake, and ADG/ADFI= feed efficiency.
[b]CONTROL= corn-soybean meal diet; IDEAL= corn-soybean meal-amino acid supplemented diet.
[c]SEM= Standard error of the mean.
[d]Diet effect, P < .05.
[e]Level effect, P < .01.
[f]Diet effect, P < .01.
[g]Level effect, P < .05.
[h]Diet effect, P < .10.
[i]Level effect, P < .10.

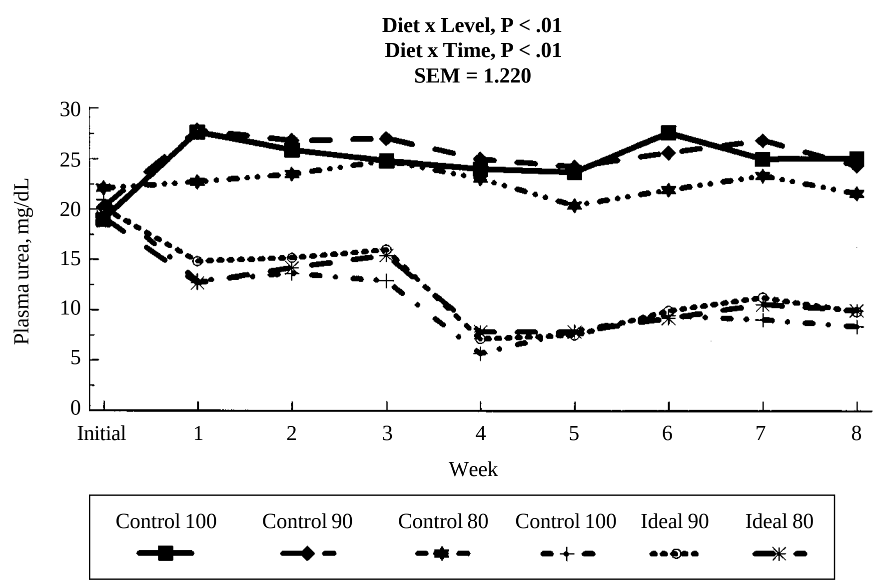

Figure 1. Plasma urea concentration in barrows fed a corn-soybean meal (CONTROL) or a corn-soybean meal-amino supplemented (IDEAL) diet at three feeding levels.

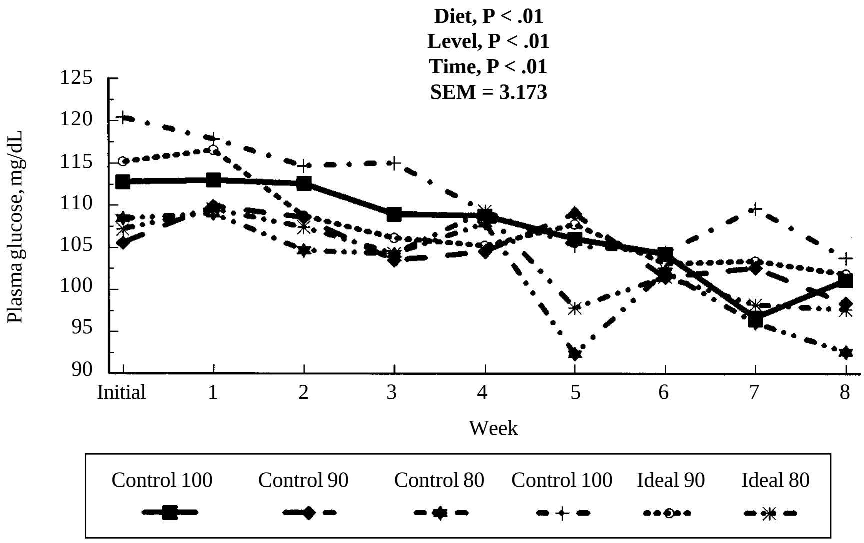

Figure 2. Plasma glucose concentration in barrows fed a corn-soybean meal (CONTROL) or a corn-soybean meal-amino supplemented (IDEAL) diet at three feeding levels.

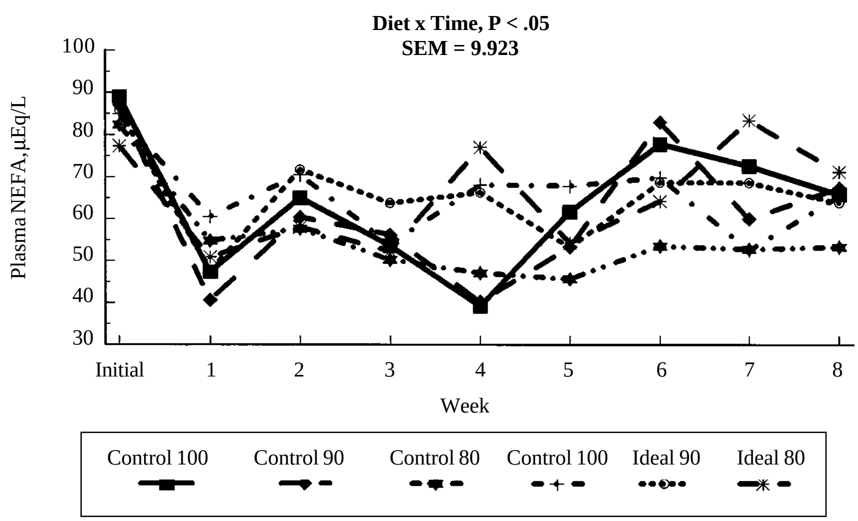

Figure 3. Plasma NEFA concentration in barrows fed a corn-soybean meal (CONTROL) or a corn-soybean meal-amino supplemented (IDEAL) diet at three feeding levels.

Table 4. Nutrient digestibilities (percent) in barrows fed control corn-soybean meal and ideal protein diets at three different feeding levels

	Diet	CONTROL[a]			IDEAL[a]			
Item	Level, %	100	90	80	100	90	80	SEM[b]
No. of pigs		6	6	6	6	6	6	
Dry matter[c]		89.05	89.63	88.79	91.13	91.95	91.92	0.536
Crude protein		83.49	84.29	82.91	82.69	83.03	82.60	0.985
Energy[c]		86.97	88.47	88.04	89.66	91.42	91.01	0.826

[a]CONTROL= corn-soybean meal diet; IDEAL= corn-soybean meal-amino acid supplemented diet.
[b]SEM= Standard error of the mean.
[c]Diet effect, P < .01.

centrations is consumed. The lower plasma urea concentrations in pigs fed the IDEAL diet may reflect both the reductions in dietary protein and that the amino acid pattern was better suited to meet the requirements for growth. Also, the lower plasma urea concentrations of pigs fed the CONTROL diet at a feeding level of 80 percent may reflect the reduction in feed intake and(or) an improved utilization of dietary amino acids compared to pigs having ad libitum access to feed or fed with a feeding level of 90 percent.

The concentrations of plasma glucose were lower in pigs fed the CONTROL diet (P < .01), were reduced as the feeding level was reduced (P < .01) and were diminished over time throughout the experiment (P < .01). Plasma NEFA concentrations were lower in pigs fed the CONTROL diet at the beginning of phase 2 (diet x time, P < .05). The physiological significance of elevated plasma glucose and NEFA concentrations in pigs fed with the IDEAL diet is unknown.

Conclusions

Regardless of feeding level, growth performance and plasma urea concentrations were reduced in barrows fed a diet formulated on an ideal protein basis. The physiological significance of elevated glucose and NEFA concentrations in pigs consuming the IDEAL diet is unknown. The reduction in daily gain observed with the IDEAL diet may suggest a deficiency of other essential amino acid(s) that may have limited the growth potential of these pigs or that the "ideal" pattern was not correct for the pigs used in this research.

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The Effect of Protein Intake on Growth Performance, Plasma Urea Concentration, Liver Weight, and Arginase Activity of Finishing Barrows and Gilts

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Summary and Implications

An experiment was conducted to evaluate the effects of dietary protein concentration on growth performance, plasma urea concentration, liver weight and liver arginase activity of finishing (138 lb) barrows and gilts. Average daily feed intake, arginase activity and plasma urea concentration were greater in barrows than in gilts, whereas liver weight was lighter in barrows than in gilts. These data suggest gilts are affected more negatively by high protein diets than barrows. We believe the changes in liver weight and urea cycle enzymes (arginase) are related to these feed intake differences.

Introduction

The 1996 Nebraska Swine Report documented a study indicating that feeding high-protein diets to finishing barrows and gilts reduced feed intake, especially in gilts. We also observed that plasma urea concentration was greater in barrows than in gilts and suggested the response of plasma urea was attributed to greater feed intake in barrows. However, the liver, the organ responsible for the majority of amino acid degradation, weighed slightly less in barrows compared to gilts. One of the possible explanations for gilts' reduced feed intake is that the activity of urea cycle enzymes is inadequate to convert the ammonia produced from high-protein diets to urea. To prevent accumulation of toxic concentrations of ammonia, then, gilts may reduce their feed intake. To test this hypothesis, the following experiment was conducted to evaluate the effect of dietary protein concentration on the activity of liver arginase, one of five enzymes in the urea cycle, in barrows and gilts.

Procedures

Thirty-six pigs (18 barrows and 18 gilts) with an initial body weight of 138 lb were allotted to a randomized complete block experiment with a 2 × 2 factorial arrangement of treatments; two sexes (barrow and gilt) and two protein levels (16 and 25 percent CP). Diets (Table 1) were corn-soybean meal-based, fortified with vitamins and minerals to meet or exceed the National Research Council requirements for 110- to 240-pound pigs. Two crude protein concentrations were obtained by changing the ratio of corn to soybean meal.

Table 1. Composition of diets, as fed basis

	Dietary protein, %	
Item	16	25
Ingredient, %		
Corn	77.25	54.10
Soybean meal, 46.5% CP	20.35	43.90
Dicalcium phosphate	.85	.35
Limestone	.45	.55
Salt	.30	.30
Trace mineral premix	.10	.10
Vitamin premix	.70	.70
Analyzed composition		
Dry matter, %	89.38	89.87
Crude protein, %	16.04	24.99
Lysine, %[a]	.81	1.46
Calcium, %	.61	.64
Phosphorus, %	.46	.49

[a]Calculated composition.

Pigs were housed individually in an environmentally regulated facility and had *ad libitum* access to feed and water throughout the experiment. Pigs were weighed, feed intakes measured, and blood samples obtained weekly to determine average daily gain (ADG), average daily feed intake (ADFI), the feed efficiency (ADFI/ADG) and plasma urea concentration. The experiment was terminated when the average body weight of pigs reached approximately 230 lb. Pigs were allowed access to feed until four to six hours before slaughter. Livers were separated and weighed

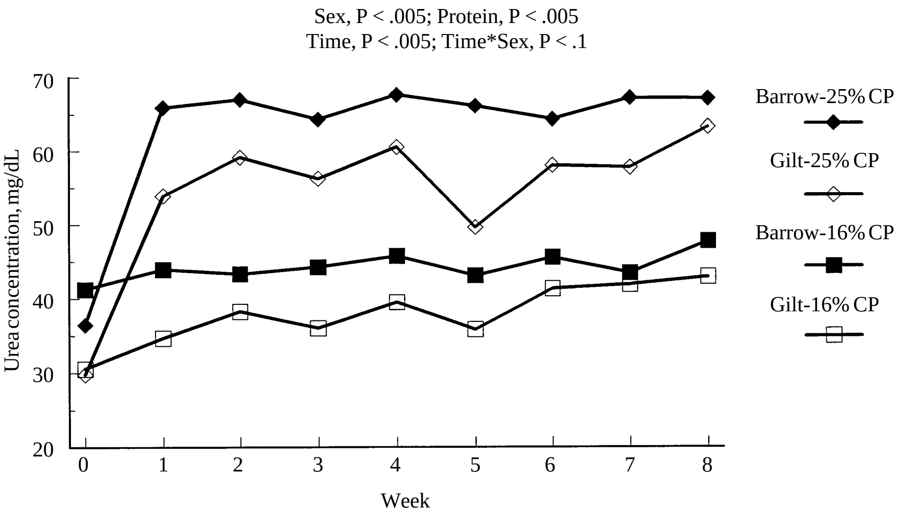

Figure 1. Plasma urea concentrations of barrows and gilts.

and liver samples were taken approximately 30 minutes after slaughter. Liver samples were frozen immediately in liquid nitrogen and kept at -80°C until analyzed for arginase activity. The unit of arginase activity was expressed as micromoles of urea formed per 30 minutes at 37°C.

Results and Discussion

Growth Performance

Average daily gain, average feed intake and feed efficiency are presented in Table 2. Because of illness, two pigs were withdrawn from this experiment. Average daily gain was reduced by 18 percent in gilts when dietary protein was increased from 16 to 25 percent, but was only slightly reduced in barrows. This resulted in a sex × protein interaction (P < .1). Average daily feed intake was greater (P < .1) in barrows than in gilts. Although feed intake was not affected (P >.1) by dietary protein concentration, it was 5 percent lower in gilts fed the 25 percent CP diet than those fed 16 percent CP. Feed efficiency was poorer in barrows than in gilts (P < .1). In addition, increasing dietary protein concentration resulted in poorer feed efficiency (P < .1). The growth performance results from this experiment were somewhat different from those reported in the 1996 Nebraska Swine Report, where the high-protein diet reduced weight gain by 10 percent and feed intake by 14 percent in gilts. The differences between the two experiments may be due to the differences in genetic background of pigs used (medium-high in the previous experiment versus medium-low lean growth potential in this experiment) and initial weight of pigs (112 versus 138 lb).

Liver Weight, Arginase Activity and Plasma Urea Concentration

Data for liver weight and arginase activity are summarized in Table 2. Data for plasma urea concentration are presented in Figure 1. No significant interactions (P > .1) between sex and protein concentration were observed. Barrows had lighter (P < .05) liver weights and greater (P < .05) arginase activities and plasma urea concentrations than gilts. Increasing the dietary protein concentration from 16 percent to 25 percent resulted in increased liver weight, arginase activity and plasma urea concentration (P < .005). The response of liver weight and plasma urea concentration to sex and dietary protein concentration in this experiment were similar to the results shown previously. Although gilts had less arginase activity per gram of liver than barrows, this difference was partially compensated by the greater liver weight of gilts. However, it remains clear that gilts are affected more negatively by high-protein diets than barrows and that gilts have lower plasma urea concentrations. These data indicate feed intake of barrows and gilts may be related to liver metabolic capacity and activity of urea cycle enzymes.

Table 2. Effect of sex and dietary protein on performance and liver arginase activity

	Sex	Barrow		Gilt	
Item	CP, %	16	25	16	25
No. of pigs		9	8	8	9
ADG, lb[a]		1.76	1.71	1.95	1.59
ADFI, lb[b]		7.15	7.05	6.79	6.42
ADFI/ADG[cd]		4.10	4.16	3.50	4.07
Liver, g[cef]		1,408	1,664	1,593	1,859
Arginase activity, µmol urea/g liver/30 min[ce]		12,313	16,370	11,624	13,458

[a]Interaction effect of sex x protein (P < .1).
[b]Main effect of sex (P < .1).
[c]Main effect of sex (P < .05).
[d]Main effect of protein (P < .1).
[e]Main effect of protein (P < .005).
[f]Warm carcass weight was used as a covariate in the statistical analysis.

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Improvement of Pork Loin Tenderness Using the Hydrodyne Process

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Summary and Implications

In this research, exposure of pork to an explosive charge within a water-filled container created an immediate improvement in tenderness and enhanced proteolysis upon subsequent storage. Hydrodyne-treated pork was as tender 1 day post mortem as untreated pork aged 40 days. The tenderness advantage of the Hydrodyne process to unaged pork is immediate and appears unrelated to proteolysis. The Hydrodyne process is a very effective tenderization technique providing benefits similar to aging.

Introduction

Pork tenderness, the main factor in meat palatability and overall consumer satisfaction, is inconsistent. The traditional methods to enhance tenderness — aging, mechanical tenderization and supplemental enzymes — require additional holding periods, space and/or labor. A technology offering immediate improvement in tenderness with minimal cost has many advantages.

The Hydrodyne process (patent numbers 5,273,766 and 5,328,403) uses a small explosive charge to generate a shock wave in water (liquid medium). United States Department of Agriculture scientists have shown (and we have confirmed) that the shock wave passes through the muscle, causing small tears which disrupt the structure and immediately enhance tenderness. Little is known about the effect of the Hydrodyne process on proteolysis and aging in pork. The objective of this study was to determine the extent to which Hydrodyne treatment alters pork tenderness and muscle proteolysis during aging.

Materials and Methods

Scientists from the USDA-Agricultural Research Service, Meat Science Research Laboratory in Beltsville, MD have worked with Hydrodyne, Inc. (San Juan, PR) to develop the technology. In this experiment, the meat was packaged twice, first in a vacuum package then in a rubber bag. The meat was supported against a steel plate (0.78 in thick) on the floor of a plastic container (55 gal capacity) so the ensuing shock wave reflected back through the meat. The explosive was composed of a liquid (nitromethane) and a solid (ammonium nitrate), neither of which are explosive until combined. The Hydrodyne process generated about 10,000 psi of force.

Two studies were conducted. Study 1 involved 24 control and 24 Hydrodyne pork loins treated one day post mortem. Study 2 consisted of paired loin pieces treated one day post mortem (12 controls and 12 Hydrodyne) then aged for 40 days. Shear force values were determined on chops (.5 in thick) cooked to an internal temperature of 162°F. After cooling, 0.5 in diameter cores (8-10 cores) were removed and sheared using a Warner-Bratzler shear blade mounted on a Food Texture Corporation Texture Measurement System.

Myofibrils to be used for electrophoresis were isolated from raw muscle samples by differential gradient centrifugation. Electrophoresis was performed to identify protein fragments with different molecular weights. Greater proteolysis results in smaller protein fragments, which settle as bands in the lower part of the electrophoretic gels.

Data were analyzed using analysis of variance and F-tests to determine the significance of differences.

Table 1. Shear force and cook loss of study 1 (unaged) pork loin pieces

	Control	Hydrodyne
Shear force, lb	12.41[a]	8.29[b]
Cook loss, %	28.81[a]	26.46[b]

[a,b]Means within a row lacking a common superscript letter differ (P < .05).

Results and Discussion

Shear force of unaged, Hydrodyne-treated pork was significantly (P<.01)

Table 2. Shear force and cook loss of study 2 (aged) pork loin pieces

	Day 1		Day 40	
	Control	Hydrodyne	Control	Hydrodyne
Shear force, lb	9.35[a]	7.74[b]	8.36[b]	8.00[b]
Cook loss, %	29.88[a]	29.64[a]	29.98[a]	28.06[a]

[a,b]Means within a row lacking a common superscript letter differ (P < .05).

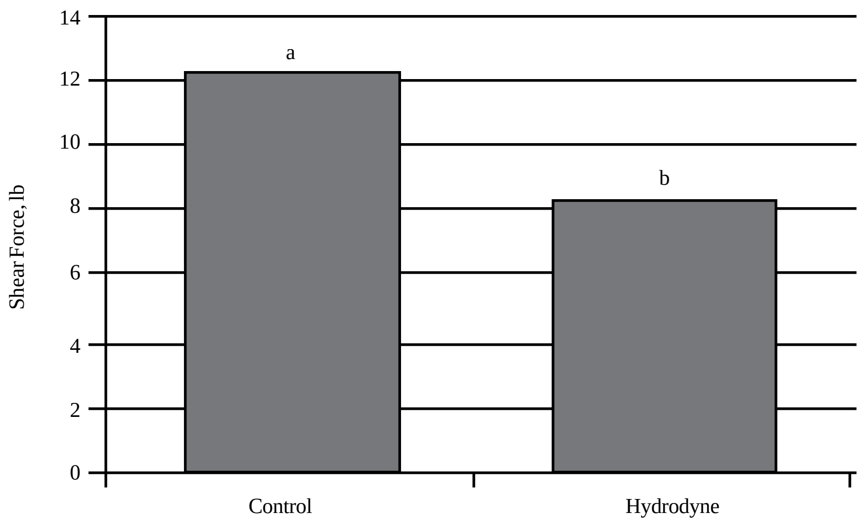

Figure 1. Shear force of pork loin pieces in study 1 (unaged, 1 day post mortem).

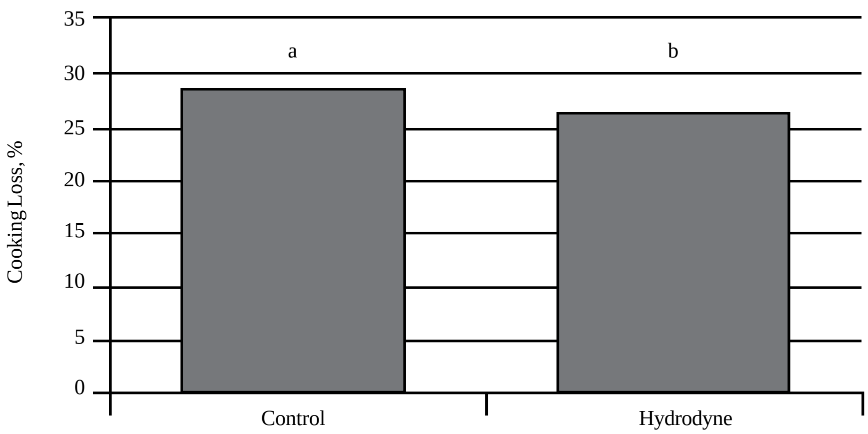

Figure 2. Cooking loss of pork loin pieces in study 1 (unaged, 1 day post mortem).

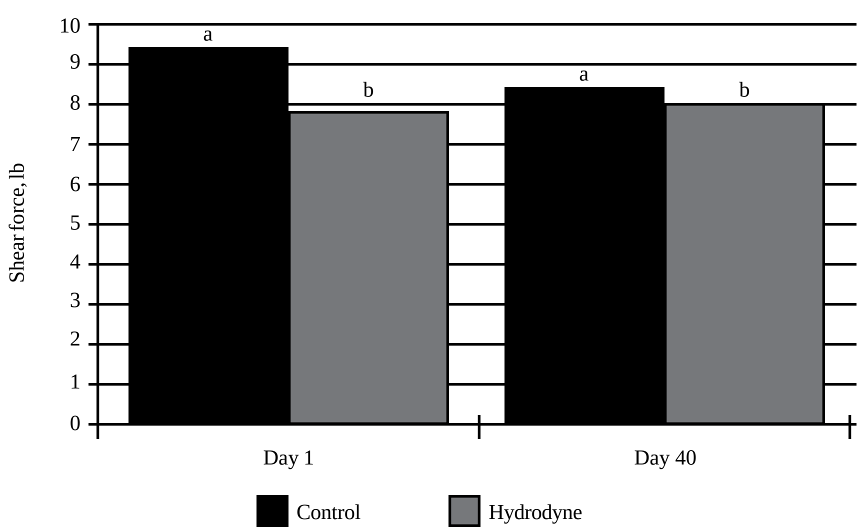

Figure 3. Shear force of pork loin pieces in study 2 (aged, 40 days post mortem).

lower (33%) than the controls (8.29 versus 12.41 pounds) in study 1 (Table 1) after one day post mortem (Figure 1). Hydrodyne-treated chops exhibited a 2.4 percent lower cooking loss (P<.05) than control chops (Figure 2).

In study 2 (Figure 3), Hydrodyne-treated pork was significantly (P < .05) more tender (17 percent lower shear force) than control pork (Table 2) one day post mortem (7.74 versus 9.35 pounds), but not at 40 days post mortem (8.00 versus 8.36 pounds). Aging improved tenderness in the control samples (P<.01) but not in Hydrodyne-treated samples (P>.05). There were no differences in cooking loss among treatments in study 2 (Figure 4). The Hydrodyne process immediately improved pork tenderness one day post mortem and aging of control and Hydrodyne-treated pork 40 days reduced the differences.

Electrophoretic gels with gradations of porosity were prepared to further evaluate proteolysis. For unaged samples (study 1), patterns on electrophoretic gels indicated a subtle, but inconsistent, benefit of Hydrodyne treatment on proteolysis (Figure 5). Smaller protein fragments, an indication of extended proteolysis, were often more frequent and in greater amount in Hydrodyne-treated pork than controls. This was not always the case one day post mortem, however, and it is difficult to draw strong conclusions from the data.

In study 2, Hydrodyne-treated samples aged 40 days clearly showed more extensive proteolysis than untreated samples (Figure 5). The location of the bands on the gels indicated degradation of higher molecular weight proteins and the presence of additional bands showed that proteolysis had occurred to a greater extent in Hydrodyne-treated pork than in the controls.

Given that Hydrodyne treatment generated greater proteolytic degradation of proteins, it was surprising that tenderness after extended aging was not different. It appears the connective

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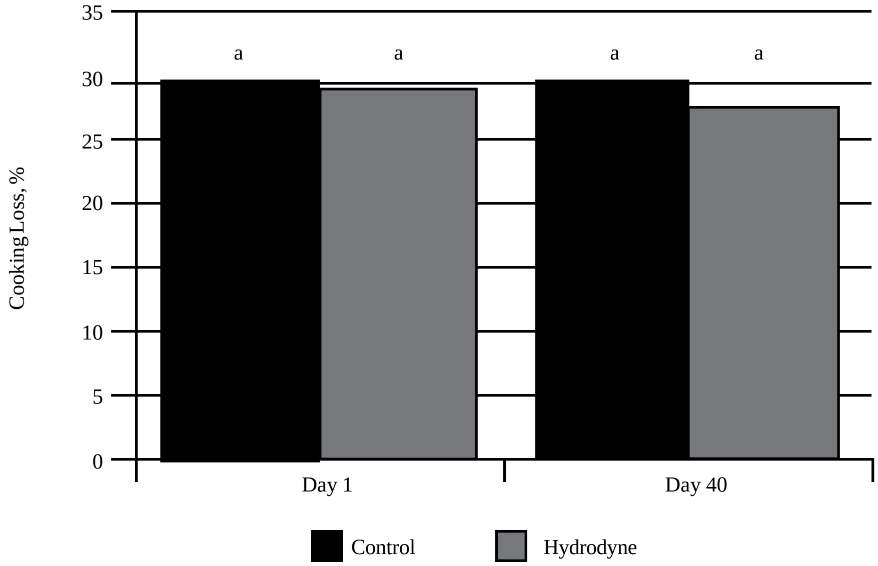

Figure 4. Cooking loss of pork loin pieces in study 2 (aged, 40 days post mortem).

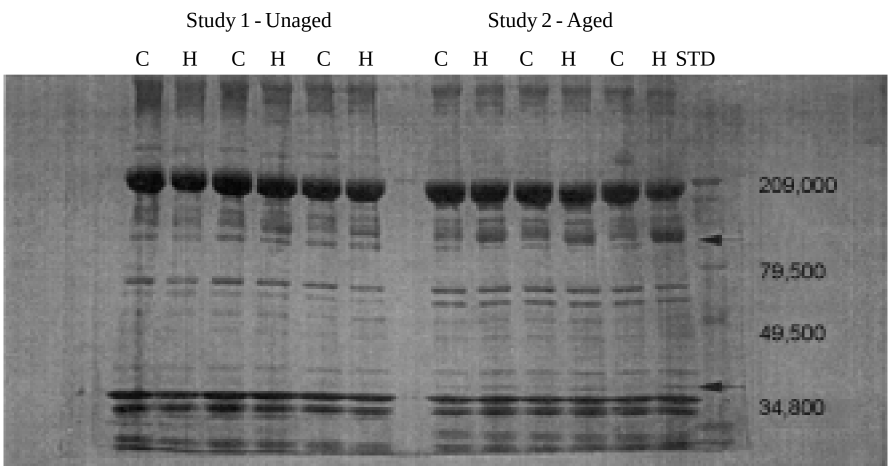

Figure 5. Electrophoretic gel of proteins from unaged (study 1) and aged (study 2) pork loin pieces.

tissue structure of muscle, which undergoes very few changes during post mortem storage, may create a limit to which proteolysis can enhance tenderness, providing a threshold tenderness level. As a result, pork aged 40 days undergoes sufficient proteolysis to become similar in tenderness to Hydrodyne-treated pork. It is also interesting to note that Hydrodyne-treated pork one day post mortem, was as tender as untreated pork aged 40 days.

Conclusions

Enhanced proteolysis does not appear to be a major mechanism of tenderization in Hydrodyne-treated pork. These data indicate tenderness of Hydrodyne-treated pork (1 day post mortem) is equivalent to pork aged 40 days. The Hydrodyne process provides an immediate tenderness advantage to unaged pork.

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Properties and Applications of Pork Trim Obtained from an Advanced Meat Recovery System

Christi M. Calhoun
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Summary and Implications

Automated mechanical systems are being utilized by the pork industry to efficiently and economically recover meat remaining on bones after fabrication. The recovered meat, referred to as pork trim-finely textured (PTFT), has unique properties which must be understood to best use this lean meat source. This research characterized the chemical and physical properties of PTFT, determined incorporation levels in ground pork and studied the storage and shelf-life-stability of products containing PTFT. Chemical and physical properties of PTFT were compared to knife trimmed meat (KT) and 80 percent lean ground pork (GP). PTFT had higher iron, calcium, total pigment and cholesterol than GP or KT. Moisture and fat content of PTFT did not differ from GP. When PTFT (0, *5, 10 and 15 percent) was incorporated into ground pork patties (10 percent and 20 percent fat), redness and sensory juiciness increased and hardness and cohesiveness decreased at all levels of incorporation. Storage stability of patties containing up to 15 percent PTFT displayed for four days under retail conditions were not affected by PTFT as measured by lipid oxidation, microbial counts and pH. PTFT obtained by mechanical recovery appears to be an exceptional substitute for pork trim in ground pork formulations. PTFT does not negatively influence, and may enhance, the attributes of ground pork when added below 15 percent. Utilization of PTFT contributes to the profitability of the pork industry which is already recognizing the benefits of mechanical recovery due to a reduction in repetitive motion syndrome, which is typically associated with knife trimming.*

Introduction

Automated systems to mechanically remove meat from bones after fabrication are being utilized in the meat industry. The machines are advantageous because they are replacing hand trimming of bones with a knife, which has caused a high incidence of repetitive motion trauma among packing plant employees in the past. The machines improve profitability, are more economical and more efficient. The mechanical systems are often referred to as Advanced Meat Recovery Systems (AMRS). One mechanism for recovering meat from bones utilizes a hydraulic piston in a perforated chamber. This machine compacts the bones without crushing or breaking, and causes the meat to be "squeezed" from the bones. These type of machines operate on the basis of different flow properties of meat and bone. At the pressures utilized by the machine, first meat flows out of the holes in the chamber, followed by fat and some connective tissue, leaving the compacted bones within the chamber. In the final phase of meat recovery, the meat passes through a desinewing machine to remove connective tissue. Due to the strong physical forces placed upon the meat and its subsequent passage through very small holes (~1.3 mm), the recovered meat has unique properties. For example, the texture is very fine, similar to finely ground pork, which may allow the recovered meat to alter texture in other products. The recovered meat may be applicable in altering texture of low fat products which tend to have undesirable texture. Mechanically recovered meats reportedly have elevated iron and increased pigment. The total pigment may enhance the color of products it is incorporated within, but high-pigment and iron content can contribute to storage stability by catalyzing lipid oxidation.

To optimize the use of this mechanically recovered meat, the physical and chemical properties must be understood. No published data is available concerning meat from the particular recovery system used in this study (Protecon TL60/Baader 605 Lean Separator). Therefore, the objectives of this study were: (1) characterize the pork from AMRS, (2) incorporate the recovered meat into ground pork formulations to determine usage levels and (3) study storage stability of pork products containing meat from AMRS.

Materials and Methods

Characterization

Untrimmed pork bones (vertebrae, neckbones, aitch, hip and scapula) were processed by a Protecon TL60 followed by a Baader 605 Lean Separator at a commercial meat plant to remove tissue from bone. The recovered meat was referred to as pork trim-finely textured (PTFT). Unprocessed bones were collected to be knife trimmed of meat at a later time. The knife trimmed meat (KT) and 80 percent lean, fresh-ground pork (GP) were used for comparison to PTFT. Analyses of these raw materials included proximate composition, cholesterol, calcium, iron, non-heme iron, total pigment, pH, expressible moisture and total collagen. Data were analyzed as a completely random design with three replications. Significance was reported at $P<0.05$.

Incorporation into ground pork

PTFT was incorporated into ground pork patties according to a 2 x 4 factorial treatment design: 10 percent or 20 percent fat and 0, 5, 10 or 15 percent PTFT. Appropriate amounts of raw materials (lean pork trim from picnic cushions, fat trim from bellies and PTFT from a commercial processor) were mixed for five minutes and ground through a 3/16 inch plate. Patties (4 oz.) were machine-formed, overwrapped on plastic foam trays with PVC film and stored under retail conditions (1076 lux light, 4^{o}C) for six days. The remaining patties were packed in double polyethylene bags and frozen at -35^{o}C.

Color of fresh patties was evaluated daily by collecting reflectance readings to calculate metmyoglobin formation and L* (lightness), a* (redness) and b* (yellowness) values over six days of storage. Frozen patties were cooked from frozen to 72^{o}C to calculate percent cook loss, change in patty thickness and diameter. Texture of cooked patties was determined using two-cycle compression to calculate hardness, springiness, cohesiveness and chewiness. A sensory acceptance panel evaluated cooked patties on an eight-point hedonic scale for flavor, texture, juiciness and overall acceptability. The experiment was conducted as a randomized complete block design replicated three times. Significance was reported at $P<0.05$.

Shelf stability

PTFT was incorporated into ground pork according to the same treatment design, manufacturing methods and packaging methods described above. On days zero, two and four of fresh retail display, patties were evaluated for color (as described above), lipid oxidation reported as thiobarbituric acid reactive substances (TBARS), pH,

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aerobic plate counts (APC) and coliforms. Sensory juiciness, flavor and overall acceptability was determined by an experienced sensory acceptance panel (n=50) using an eight-point hedonic scale. Frozen patties were evaluated on weeks zero, four, eight and 12 for lipid oxidation only. The experimental design was a randomized complete block design replicated three times with data analyzed according to repeated measures techniques. Significance was reported at P<0.05.

Table 1. Characterization of pork trim-finely textured (PTFT), knife trim pork (KT) and ground pork (GP)

	Treatment			
Variable	PTFT	Knife Trim	Ground Pork	SEM‡
Moisture (%)	65.81	67.01	64.33	0.92
Fat (%)	18.94	16.19	18.44	1.28
Protein (%)	15.38[a]	17.24[ab]	18.04[b]	0.59
Ash (%)	1.14[b]	0.93[a]	0.92[a]	0.05
Cholesterol (mg/100g meat)	101.67[c]	72.33[b]	62.33[a]	2.49
Calcium (mg/100g meat)	107.50[c]	26.77[b]	6.12[a]	5.53
Total Iron (mg/100g meat)	3.24[b]	1.11[a]	1.20[a]	0.10
Nonheme iron (µg/g meat)	5.96[b]	2.46[a]	4.07[ab]	0.68
pH	6.39[b]	6.47[b]	6.12[a]	0.03
Expressible moisture (%)	32.33[b]	30.46[b]	27.77[a]	0.62
Total pigment (mg/g meat)	5.87[b]	2.41[a]	2.16[a]	0.18
Total collagen (mg/g meat)	5.34[a]	12.85[b]	11.58[b]	0.49

‡Standard error of the mean.
[abc]Means within a row with different superscripts are different (P<0.05).

Results and Discussion

The fat and moisture content of PTFT (Table 1) did not differ (P>0.05) from GP, which may indicate PTFT could be a useful substitute for 20 percent fat trimmings commonly utilized in ground and processed meat formulations. The composition of mechanically recovered meats has varied, based on the specific recovery process, bone type, species and amount of lean attached before processing. The ash content was higher for PTFT compared to KT and GP which may indicate presence of very small bone particles. PTFT had a higher calcium content than GP or KT (P<0.05) but was well below the USDA allowable limit of 150 mg/100 grams meat. The higher (P<0.05) cholesterol content of PTFT versus KT or GP may be due to the expression of blood and marrow cells from the soft interior of the bone during the recovery process. Blood provides a transport pathway for cholesterol. The effect of PTFT cholesterol content on cholesterol in a final product would be minimal, due to the low usage levels commonly practiced in industry with meat from AMR. Total iron was higher for PTFT versus GP and KT (P<0.05). The majority of the iron was in the heme form as determined by difference using the nonheme values. The higher total iron may be attributed mostly to incorporation of the oxygen transporting heme protein, or hemoglobin, when pressure exerted on bones during recovery forces the release of iron-containing bone fluids through the porous bone structure. Iron alone, and in the form of heme pigments and non-heme iron, have been implicated as catalysts in lipid oxidation which may contribute to reduced shelf life and stability of mechanically recovered meats.

The higher total pigment of PTFT compared to GP and KT is likely due to incorporation of heme pigments, specifically hemoglobin, from the bone soft interior. The color intensity of mechanically recovered meat may provide a desirable benefit to certain prod-

Table 2. Fat and PTFT main effects on ground pork patty proximate composition, cook yield, cook dimensions, texture and sensory acceptability

	Fat			PTFT				
Variable	10%	20%	SEM‡	0%	5%	10%	15%	SEM‡
Fat	8.62	17.88*	0.38	13.21	13.16	13.26	13.35	0.43
Moisture	73.32	65.89*	0.40	69.40	69.66	69.76	69.62	0.45
Protein	19.10	17.12*	0.13	17.88	18.34	18.19	18.05	0.19
Ash	1.10	0.98*	0.02	1.05	1.05	1.01	1.05	0.02
Expressible Moisture (%)	34.77	35.44	0.50	36.49	34.74	34.90	34.25	0.80
Cook yield	73.50	73.07	0.50	72.69	73.48	73.70	73.34	0.73
Change in diameter (%)	20.29	19.69	1.85	18.29	20.62	19.69	21.32	2.31
Change in thickness (%)	8.31	6.94	0.94	6.44	8.48	6.18	9.39	1.41
Hardness (N/g)	13.12	11.05*	0.32	13.11[a]	11.70[b]	12.40[ab]	11.14[b]	0.48
Cohesiveness (unitless)	0.59	0.52*	0.02	0.58[a]	0.55[b]	0.55[b]	0.54[b]	0.02
Springiness (mm)	22.92	21.08*	0.22	22.33	21.72	22.11	21.83	0.33
Chewiness (J/g)	0.17	0.12*	0.02	0.17[a]	0.14[b]	0.15[ab]	0.13[b]	0.02
Texture	5.44	5.42	0.11	5.20	5.48	5.66	5.36	0.16
Juiciness	5.13	5.46*	0.09	4.90[a]	5.32[b]	5.54[b]	5.42[b]	0.14
Flavor	5.07	5.06	0.09	4.79	5.08	5.28	5.07	0.14
Overall Acceptability	5.18	5.24	0.10	4.89	5.28	5.46	5.21	0.15

‡Standard error of the mean.
*Means in a row within fat level are different (P<0.05).
[ab]Means in a row within PTFT level with different superscripts are different (P<0.05).

Table 3. Main effect of day on sensory acceptance and color of ground pork patties

	Day				
	0	2	4	SEM‡	Effect[a]
Sensory acceptance					
Juicy	5.23	5.07	5.07	0.05	L
Flavor	4.97	4.90	4.78	0.05	L
Overall acceptability	5.00	4.89	4.80	0.04	L
Color					
L* (lightness)	57.67	56.01	55.43	0.18	Q
a* (redness)	30.79	25.68	20.74	0.24	L
b* (yellowness)	21.64	19.29	17.28	0.12	L
Metmyoglobin	24.62	30.63	39.83	0.56	Q

‡Standard error of the mean.
[a]L=linear and Q=quadratic (P<0.05).

ucts in terms of enhanced consumer perception, but could cause concern in light-colored products, such as white sausage. The collagen content, an indication of connective tissue, was lower in PTFT than GP or KT (P<0.05). The low collagen value of PTFT is an important attribute which will not limit usage levels in other processed products. The pH of PTFT was similar to KT (P>0.05) and both were higher than GP (P<0.05). The high pH of some other mechanically recovered meats has been attributed to bone marrow, which has a pH of 6.0 - 7.0. The higher pH did not contribute favorably to expressible moisture, as moisture loss was higher for PTFT and KT versus GP (P<0.05). The higher expressible moisture of PTFT may be a result of the small particle size created during the recovery process which increases the overall surface area and may offset the moisture retention possibilities normally related to high pH.

When PTFT was incorporated into ground pork patties, it did not affect (P>0.05) moisture, fat, protein or ash which illustrates PTFT can be added up to 15 percent without significantly altering patty proximate composition (Table 2). PTFT did not affect cook yield, cooked patty dimensions or springiness of ground pork patties (P<0.05). Addition of PTFT resulted in a patty that was generally softer, less cohesive and less chewy (P<0.05) than 0 percent PTFT patties. Other research on mechanically recovered meat has shown levels of addition above 15 percent created a too-soft ground product. The 10 percent fat patties were harder, chewier, more springy and more cohesive (P<0.05) than the 20 percent fat patties, but PTFT had no effect on texture of the low-fat formulation as hypothesized. Expressible moisture of raw patties was not affected by PTFT (P>0.05) despite PTFT alone displaying greater expressible moisture than 80 percent lean ground pork (Table 1). Texture rated by a sensory acceptance panel was not affected by PTFT or fat. Panelists rated the juiciness of product containing any level of PTFT as more desirable than zero percent addition. Neither flavor nor overall acceptability of patties were affected by fat or PTFT (P>0.05). Patties became redder and darker (P<0.05) with PTFT addition, but over days of storage, PTFT did not affect patty color (data not shown). Surface metmyoglobin was not affected by fat or PTFT (P>0.05; data not shown). Metmyoglobin is the brown-gray pigment in meat considered undesirable by consumers.

In the study conducted to determine shelf stability, color and sensory acceptance, data for the main effects of PTFT and fat in ground pork patties was similar to the results of the prior study, so only day effect is reported and discussed for these attributes (Table 3). The sensory attributes of juiciness, flavor and overall acceptability declined (P<0.05) during retail display. The patties became darker, less red, less yellow and had increased metmyoglobin content during the display period. Lipid oxidation, as measured by TBARS, was not affected by PTFT or fat (P>0.05), but increased (P<0.05) during days of retail display (Table 4). TBARS values on day four remained below 1 mg malonaldehyde/kg meat, which is considered the point of unacceptance for raw product. Lipid oxidation of frozen patties was not affected by PTFT (P>0.05) but was explained by a fat x week interaction (P<0.05; data not shown). Lipid oxidation of 10 percent fat patties decreased more during 12 weeks of storage than 20 percent fat

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Table 4. Main effects of fat, pork trim-finely textured (PTFT) and day on lipid oxidation, pH, aerobic plate count, and coliform data for ground pork patties

	Fat			PTFT						Day				
	10%	20%	SEM‡	0%	5%	10%	15%	SEM‡	Effect[a]	0	2	4	SEM‡	Effect[a]
Lipid Oxidation (TBARS[b])	0.81*	0.66	0.03	0.75	0.72	0.69	0.77	0.04	NS	0.57	0.69	0.94	0.04	L
pH	6.08	6.08	0.01	6.08	6.09	6.07	6.09	0.01	NS	6.05	6.13	3.06	0.01	Q
Aerobic Plate Count (log_{10} cfu/g)	6.63	6.61	0.04	6.63	6.62	6.66	6.58	0.05	NS	5.32	6.66	7.87	0.05	L
Coliforms (log_{10} cfu/g)	2.90	2.86	0.08	2.82	2.87	2.90	2.93	0.11	NS	2.32	2.65	3.68	0.10	Q

‡Standard error of the mean.
[a]NS=not significant, L=linear and Q=quadratic (P<0.05).
[b]TBARS reported as mg malonaldehyde/kg meat.
*Means in a row within fat level are different (P<0.05).

patties. However, the rate of change was not greater than 0.2 mg/kg meat. The pH of the patties was not affected by PTFT, fat or day (P>0.05; Table 4). Aerobic plate count and coliforms were not affected by PTFT or fat (P>0.05). Both microbial indicators increased during retail display but remained at acceptable levels.

Conclusions

The inherent properties of pork trim-finely textured (PTFT) do not differ dramatically from knife-trimmed pork for most attributes related to functionality, making PTFT a potential economical ingredient to replace lean trimmings in ground or emulsified products. When PTFT was incorporated into ground pork patties, juiciness and color improved. The higher total pigment content of PTFT increased redness of patties, which may increase consumer appeal for ground pork by enhancing the desired bright red color. PTFT had no adverse effect on fresh pork lipid oxidation, microbial counts, color, sensory acceptability or frozen ground pork lipid oxidation during storage. Therefore, storage stability does not appear to be a concern when PTFT was incorporated up to 15 percent in ground pork.

[1]Christi M. Calhoun is a graduate student, Roger W. Mandigo is a professor with the Department of Animal Science.

Utilization of Raw Pork Skins in Reduced Fat Fresh Pork Sausage

Tammy Fojtik
Roger Mandigo[1]

Summary and Implications

The effects of fat, raw pork skin and added water on the color, yield, texture and palatability of fresh pork sausage were investigated. Fresh pork sausage was produced to contain 8 percent and 20 percent fat, 10 percent or 20 percent pork skin and zero percent or 10 percent added water. Three controls were produced at 8 percent, 20 percent and 35 percent fat with no added pork skin or water. Sausage with added pork skins had increased pH values. The 8 percent fat sausage and sausage without added water had the greatest cook yields, while the addition of pork skin did not affect cook yield. Pork skins and added water caused sausage to be lighter in color. Redness of the sausage was similar for 20 percent fat/20 percent pork skin sausage compared to the 35 percent fat control. Kramer shear values indicated added water made sausage softer. Added pork skin did not affect Kramer shear values. A sensory panel rated 10 percent pork skin sausage more tender than sausage with 20 percent pork skin. Sausage with 8 percent fat and 10 percent pork skin was rated higher for juiciness and overall acceptability when compared to 8 percent fat sausage with 20 percent pork skin and 20 percent fat sausage at both added pork skin levels. Pork skins were successfully incorporated into reduced fat-fresh pork sausage. Production of acceptable reduced-fat pork sausage with added pork skins would increase the demand for this pork sausage and add value to a by-product of the pork industry.

Introduction

Fresh pork sausage is a comminuted meat product that has remained relatively unaffected by the drive to reduce-fat content in processed meats. United States Department of Agriculture regulations state fresh pork sausage may contain no more than 50 percent fat. Technology to reduce fat for this product is being investigated.

Reduced- or low-fat meat products tend to be less juicy, less desirable in flavor and less tender when compared to higher fat products. Consumers, however, continue to demand lower fat content in foods. The challenge is to produce reduced-fat meat products that also maintain acceptable sensory characteristics so consumers can purchase meat products meeting both their dietary and palatability desires. The reduction of fat in fresh pork sausage offers new products for consumers who demand less fat in meat products. The functionality of pork skins (a by-product pork processing) may be important for use in reduced-fat meat product technology through improved palatability. Utilization of this by-product would increase profitability for operations generating pork skins.

The purpose of this study was to determine the effects of fat, pork skin and added water on fresh pork sausage yield, color, texture and palatability.

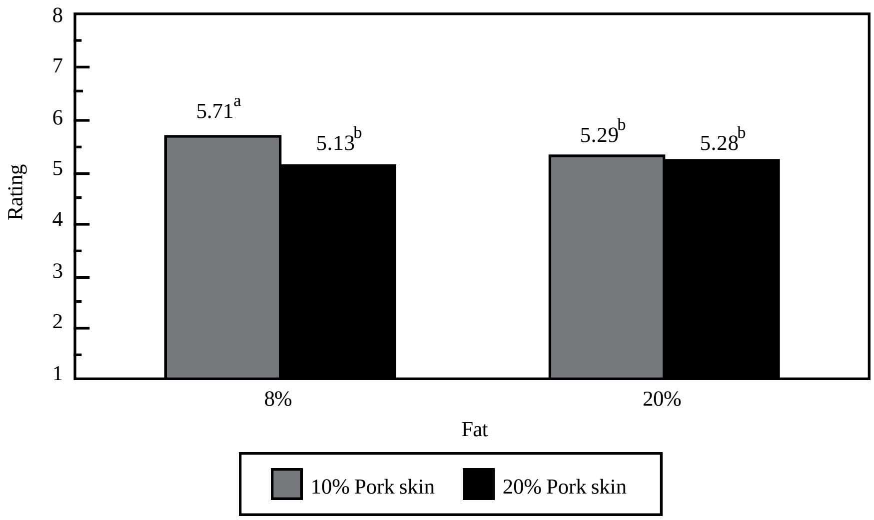
Methods

Fresh pork skins from hams were obtained from a commercial processor. The skins were cut into strips, ground to .5 in, spread on plastic-lined metal trays and frozen (-18°C) overnight. They were then broken apart and fed through a 1.5 mm head on a Comitrol flaker. Flaked skins were kept frozen (-23°C) until utilized in the

Table 1. Effect of fat, pork skin, and added water on pH, color and cook yield

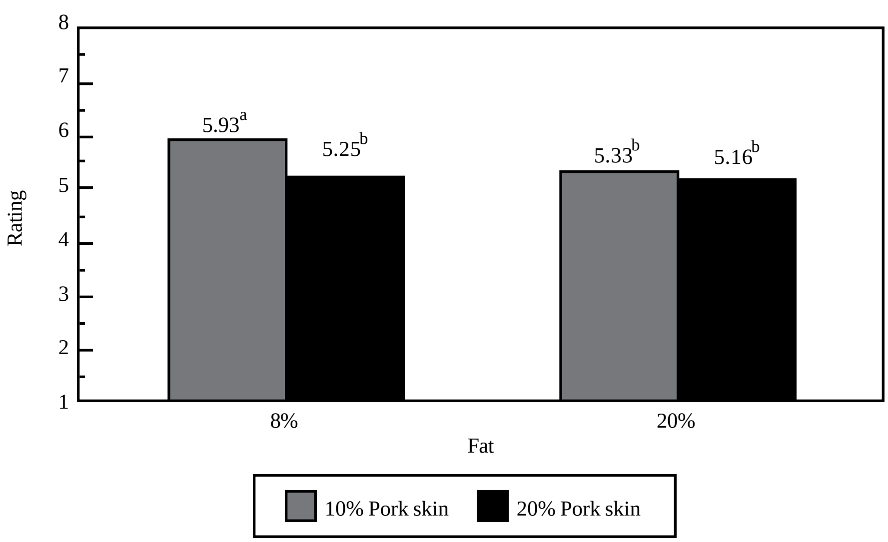
	Fat		Pork Skin		Added Water	
Variable	8%	20%	10%	20%	0%	10%
pH	6.07	6.04	6.03[a]	6.08[b]	6.03	6.07
L* (lightness)	51.91[a]	60.45[b]	55.10[a]	57.27[b]	54.94[a]	57.42[b]
a* (redness)	23.39[a]	20.01[b]	22.01	21.40	22.30	21.10
b* (yellowness)	19.47	19.45	19.65	19.27	19.74	19.18
Cook yield (%)	76.16[a]	67.65[b]	71.02	72.79	73.91[a]	69.90[b]
Peak force (N/g)	29.42	32.84	29.84	32.42	34.40[a]	27.86[b]
Total energy (J/g)	0.36	0.37	0.35	0.38	0.40[a]	0.33[b]

[ab]Means with unlike superscripts are different (P < 0.05).



[ab]Means with unlike superscripts are different (P<0.05).

Figure 1. Effect of fat and pork skin on juiciness.



[ab]Means with unlike superscripts are different (P<0.05).

Figure 2. Effect of fat and pork skin on overall acceptability.

pork sausage.

Sausage was manufactured by grinding lean and fat trimmings to .5 in. Batches were mixed with a commercial seasoning blend for five minutes then ground to .2 inches. The mixture was stuffed into 2.5 inch casings and frozen (-23°C) for 24 hours. Chubs were sliced with a bandsaw into .5 inch-thick patties weighing approximately 43 grams. Patties were vacuum packaged and kept frozen (-23°C) until further analysis.

The experiment was replicated three times. Sausage was analyzed for proximate composition, pH, cook yield and raw color. Objective texture measurements were obtained through Kramer shear peak force and total energy. A sensory panel evaluated sausage samples for tenderness, juiciness, flavor and overall acceptability.

Results and Discussion

The addition of pork skin in fresh pork sausage caused increased (P<0.05) pH (Table 1). Pork skins have a pH of 7.06, compared to 5.6 - 5.7 for normal meat. Higher pH in meat products usually results in greater water-holding capacity, which could increase juiciness of the sausage.

Table 1 also shows L*, a* and b* values for uncooked sausage. The L* measures lightness (higher value indicates lighter color), a* measures redness (higher value indicates redder color) and b* measures yellowness (higher value indicates more yellow color). Higher fat, pork skin and added water levels resulted in lighter colored sausage, due to dilution of lean pigments by increased fat, pork skin or added water. Lower-fat sausage was redder (higher a* values) because less fat was present in the sausage, allowing for lean color to predominate. Added pork skin and water did not affect (P>0.05) redness of the sausage. No differences were detected for yellowness (b*).

Lower-fat sausage had higher (P<0.05) cooking yields (Table 1). The 35 percent fat control sausage had the

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lowest (P<0.05) cooking yield (56.58%; data not shown). Increased added water also decreased (P<0.05) cook yield because more moisture is available to lose during the cooking process. Addition of pork skins into sausage did not affect cook yields.

Kramer shear measurements (Table 1) indicated sausage with added water required less force and energy to shear. Added water also caused a softer-textured sausage. Added pork skins did not affect Kramer shear values.

A sensory panel evaluated the sausage for tenderness, juiciness, flavor and overall acceptability on an eight-point hedonic scale. Panelists rated 8 percent fat sausage more tender (P<0.05) than 20 percent fat sausage, which is contradictory to the tenderness problem commonly associated with reduced-fat meat products. Panelists rated 8 percent fat sausage with 10 percent pork skin higher (P<0.05) in juiciness (Figure 1) and overall acceptability (Figure 2) than 8 percent fat sausage with 20 percent pork skin and 20 percent fat sausage at both levels of pork skin addition.

Conclusions

Increased levels of pork skin increased sausage pH. Added pork skin caused sausage to be lighter in color but did not influence redness. Sensory panelists preferred sausage with 10 percent pork skin over sausage with 20 percent pork skin. Pork skin not only can offer improvements in sensory characteristics of reduced-fat pork sausage, but also identifies a possible use for a by-product of the pork industry.

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[1]Tammy Fotjik is a graduate student and Roger W. Mandigo is a professor with the Department of Animal Sciece.

Pen Space Allocations and Pelleting of Swine Diets

Mike Brumm[1]

Summary and Implications

An experiment was conducted to determine whether an interaction exists between pen space allocation (14 versus 19 pigs per pen in 8 x 14 ft pens) and physical form of the diet (meal versus pellet) in a fully slatted facility. There were no interactions between diet form and pen space allocation for daily gain, feed intake or feed conversion efficiency. Pigs fed pelleted diets had a 2.3 percent improvement in daily gain and a 7.9 percent improvement in feed efficiency. Although pigs housed 14-per-pen grew faster than those housed 19-per-pen with no difference in feed conversion efficiency, pigs in the 19-pig pens produced 30 percent more live weight gain per square foot of pen space during the 106-day trial. There were no differences in death loss or body weight variation within the pens of pigs. These results suggest the response to pelleting is similar, regardless of pen space allocations and that pen space allocations affect not only pig performance, but also weight gain per unit of pen space. This has implications for income-per-unit of facility cost.

Introduction

As pork producers increase their investments in confinement facilities, they increasingly pay attention to management practices to increase the net income-per-unit of space. This generally means space allocations for growing-finishing pigs are less than those considered optimal for maximum daily gain and feed conversion efficiency. As a consequence of these space restrictions, daily feed intake is reduced. There are reports in the scientific literature indicating this reduction in feed intake associated with space restrictions can be modified if the diet is pelleted. The purpose of the following experiment was to examine whether an interaction exists between pen space allocation and physical form of the diet (pellet or meal).

Methods

Terminal-cross barrows and gilts were allotted to treatments consisting of either 14 or 19 pigs per pen (8 versus 5.9 ft^2/pig, respectively). The pigs were offered diets either as pellets or in meal form from arrival following purchase to slaughter.

The experiment was conducted at the University of Nebraska's Northeast Research and Extension Center at Concord from November, 1996 to March, 1997. The facility was a fully slatted, double-wide, naturally ventilated barn with fresh water under-slat flushing for manure removal. Pen size was 8 ft x 14 ft. There were two nipple drinkers and four feeder spaces provided in each pen.

Diets were formulated to contain 1.00, 0.95, 0.85 and 0.70 percent lysine and were switched on the week that individual pens of pigs averaged 80, 130 and 190 lb live weight, respectively. The ingredient composition of the meal and pellet diets was identical, as was the fineness of grind (Table 1). The only difference in diet form was the steam conditioning and pelleting of the pellet diet.

Results

Originally, the experimental design called for the collection of carcass

Table 1. Experimental diets

Item	Pig bodyweight, lb			
	40-80	80-130	130-190	> 190
Ingredient				
Corn	1164	1199	1278	1388
Soybean meal, 44% CP	430	395	320	211
Wheat midds	300	300	300	300
Cane molasses	50	50	50	50
Calcium carbonate	21	21	21	23
Dicalcium phosphate	17	18	14	12
Salt	7.5	7.5	7.5	7.5
Lysine•HCl	3	3	3	3
Vitamins/trace minerals	7.5	6.0	6.0	6.0
Calculated analysis				
Energy, ME/lb[a]	1447	1448	1455	1460
Lysine, %	1.00	.95	.85	.70

[a]ME = metabolizable energy

Table 2. Effect of experimental treatments on pig performance

Item	Diet form		Pigs/pen		SE[a]	*P* values	
	Meal	Pellet	14	19		Diet	Space
No. pens	8	8	8	8			
Pig weight, lb							
Initial	42.9	42.6	42.7	42.9	.2		
d 106	229.3	233.3	235.3	227.3	1.1	<.05	<.01
CV d 106[b]	7.8	8.0	8.1	7.7	.4	NS	NS
Average daily gain, lb	1.76	1.80	1.82	1.74	.01	<.05	<.01
Average daily feed, lb	5.57	5.25	5.56	5.26	.06	<.01	<.01
Feed:gain	3.17	2.92	3.06	3.02	.03	<.01	NS
No. pigs dead	0	3	1	2		NS	NS

[a]Standard error.
[b]Coefficient of variation for pig weight at day 106.

lean and hot carcass weight on individually identified pigs, with entire pens slaughtered on the week the heaviest pig in the pen weighed 280 pounds or greater. On the second week of slaughter, however, a consulting veterinarian diagnosed pigs with a respiratory complex (most likely pasteurella pneumonia with secondary mycoplasma pneumonia). Because performance was severely compromised during the previous week, pig performance data are only reported to day 106 of the experiment, when the first pigs weighed at least 280 pounds.

The only interaction of diet form and space allocation occurred within pen weight variation as measured by CV (coefficient of variation) on day 106. Pigs fed pelleted diets had an increase of within pen CV when the number of pigs per pen increased from 14 to 19 (7.5 versus 8.5 percent). The CV decreased, however, if the diet was in meal form when the number of pigs per pen increased from 14 to 19 (8.7 versus 6.9 percent). However, the overall CV's are low compared to previous research trials, and the amount of change between the various treatments was small.

Table 2 presents the main effects of diet form and pen space allocation on pig performance to day 106. Pelleting the diet resulted in an improvement (P < .05) in daily gain and feed efficiency and a decrease (P < .01) in daily feed intake. The 7.9 percent improvement in feed efficiency for the pellet versus meal diets is typical of other reports and within the 5-8 percent range suggested by the University of Nebraska's Swine Nutrition Guide. The 2.3 percent improvement in daily gain is just under the 3-6 percent suggestion in the same publication. The slightly lower daily gain response may be explained because the experiment was conducted during the winter.

Increasing the number of pigs per pen from 14 to 19 resulted in a decrease (P < .01) in both daily gain and daily feed intake, with no effect on feed conversion efficiency. These results agree with earlier published studies from the same research facility documenting a consistent decrease in daily feed intake and daily gain when pen space allocations are decreased, but an inconsistent response on feed conversion efficiency.

Another method of comparing pig performance is to calculate the net pounds of gain per square foot of pen space during the 106-day period. The 19-pig pens averaged 31.3 lb of live weight gain per square foot of pen space versus 24.1 lb of gain for the 14-pig pens, a 30 percent increase, with no difference in death loss or weight variation within pens.

Three pigs of the original 264 pigs died. Causes of death were twisted gut, bleeding ulcer and undetermined. There was no effect (P>.15) of experimental treatment on death loss, although all three pigs were offered pelleted diets.

Conclusion

Unlike previously published reports in the scientific literature, these results suggest no interaction between pen space allocation and physical form of the diet for growing-finishing pigs. The response to pelleting was similar for crowded and uncrowded pigs for both daily gain and feed conversion efficiency.

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Building Loads and Failures

Gerald R. Bodman[1]

Summary and Implications

During the investigation of a collapsed building, inadequate design loads and inappropriate construction practices are often discovered. A building failure adversely affects a producer's ability to generate income. A well-designed and constructed building costs only slightly more than a mediocre one. Insisting on good design, use of high-quality materials and a qualified contractor reduces the risk of structural failure.

Introduction

Choosing an appropriate agricultural building design load is a task often assigned to the rural builder or building manufacturer. Unfortunately, in an attempt to lower design costs, the selected design loads are often lower than recommended. Despite published design load guidelines, the lack of enforcement and lack of specific design codes frequently results in "as built" agricultural buildings having a low load-carrying capability.

The lack of design codes for agricultural buildings or of load guidelines enforcement contrasts the controls placed on buildings constructed for commercial or industrial use in most metropolitan areas. Most states also have established additional "fire and panic" or life safety regulations which set forth minimum state wide regulations for public buildings.

Obviously, there is little room for argument regarding the importance of designing a building to reduce the risk of losing human life. This argument, however, can be applied to all buildings, because people are present at sometime in **all** buildings. When considering agricultural production facilities, the possible loss of productive capability also warrants consideration. A structural failure directly affects a producer's income-generating ability. Many people argue the problem is not with design loads but with construction techniques. Evidence indicates both areas need improvement.

Causes of Structural Failure

Sometimes, builders fail to recognize or understand the different load-carrying capacities of different species and grades of lumber. Lumber price and availability contributes to this problem. Most lumber suppliers offer minimal choice of lumber species or grade.

Lighter design loads usually require less or lower-quality materials, reducing construction costs. However, because labor is typically about half the cost of erecting a building, the cost of using a good quality 2 inch x 10 inch rafter instead of a 2 inch x 8 inch or mediocre quality 2 inch x 10 inch rafter is relatively insignificant when viewed against the overall cost of the building. Except for a grade stamp, there is no practical way for the end-point user to determine the wood's species, grade or strength characteristics.

Another concern is failure to recognize the limitations of various structural materials. One example is using water-based adhesives to fabricate trusses or other structural components for agricultural buildings. All livestock buildings have high enough internal humidity levels to cause water-based glues and adhesives to deteriorate. Practically speaking, only deterioration rate varies between buildings. Inspection of several failed buildings revealed an outline of glue on gusset and/or truss member contact areas but bonding at the glue line was non-existent. In one situation, glue deterioration occurred in less than 10 years; in another case 10 to 12 years passed before failure occurred. Coupled with a gradual deterioration and loosening of other mechanical fasteners such as staples or nails, both buildings failed at relatively light imposed roof loads. Failure to utilize polyethylene vapor barriers and provide good ventilation contributed to the failure of these two buildings.

Another construction deficiency is an apparent lack of understanding concerning the load carrying or load transfer capabilities of nails and bolts. The influence of grain orientation and fastener position within the wood on load carrying capacity appears to be poorly understood. Whether a fastener is loaded in single shear (2-member joint) or double shear (3-member joint) also significantly affects load carrying capacity. Many builders rely heavily on toe-nailing to develop load transfer joints. The load carrying capacity of a **properly installed** toe-nail is about half the allowable load for shear or withdrawal for a nail installed in the conventional manner. Because of this, many building failures start as joint failure.

Recommended roof design loads are listed in Table 1. The values in Table 1 include a 5 pounds per square foot (psf) allowance for the weight of the structure, plus accumulated snow loads.

With rare exceptions (for example, tall buildings) wind loads are not a major roof design factor for agricultural facilities in Nebraska. However, wind loads must be considered when

Table 1. Recommended minimum total roof design loads for agricultural buildings in Nebraska (weight of structure and snow)

Building Use	Roof Design Loads, psf*
Temporary range and pasture shelters	10
Hay storages	15
Grain and machinery storages	20
Livestock confinement	25

*Increase loads by at least 5 psf for buildings with shingle roofs; roofs with slopes of 3:12 or less; and for buildings in heavy snowfall areas.

designing sidewalls, end walls, doors and such. Upward forces imposed by wind loads determine the need for bracing of truss members, lateral/longitudinal bracing of the overall structure, pole or post embedment and uplift forces at truss-to-post joints. The minimum recommended wind design load is 15 psf. Higher loads are needed for buildings with eave heights greater than 16 feet. A load of 20 psf, roughly the equivalent to an 88 mph wind, is recommended for tall buildings, buildings important to a farming operation and for lower-profile buildings in exposed locations. Loads other than wind, snow and weight of a structure, (i.e., the weight of stored products, suspended feeders, poultry cages, cranes, etc.) should be added to the loads in Table 1 to determine the total roof design loads.

Many designers believe "zero" failure designs are impractical and noneconomical. That philosophy is not appropriate for the designer, builder or producer building the structure. The loss of a livestock building during winter conditions can be devastating. In addition to the direct loss of livestock, productivity is adversely affected — often for many months. Buildings are commonly insured for the direct cost of the structure, but there is no practical way to insure against the loss of production. For example, a purebred pork producer with many valuable animals may never be able to re-establish the genetic base. Such losses are generally not insurable.

Causes of structure failures investigated during the past five years include:

1. Lack of longitudinal bracing of truss members loaded in compression. Members buckled and failed. (three buildings)
2. Corrosion of truss plates. Truss failed at mid-span joint.
3. Non-preservative-treated post rotted. Wall pushed out.
4. Inadequate embedment and/or anchorage. Building posts pulled from ground during moderate wind storm.
5. Inadequate fastening at truss-to-post joint (eave of building). Joint pulled apart during moderate wind storm.
6. Inadequate anchorage of grain bins. Bins pulled loose from footing and were destroyed during moderate winds.

Designing for excessively heavy loads can make buildings uneconomical or unaffordable. At the same time, producers should assure the building they purchase will meet their needs with minimum risk of adverse influence on their income-producing ability. Avoid constructing both buildings with an expected life of hundreds of years and those which will fail with the first gust of wind or first few flakes of snow are both unwise.

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Ventilation Systems — Redundancy is Essential

Gerald R. Bodman[1]

Summary and Implications

Ventilation system failure can kill many animals in a few minutes. This kind of loss is often non-insurable. Adequate backup systems can reduce the risk of loss. Producers should install backups, or system redundancy, consistent with the level of risk they consider acceptable.

Introduction

"Fans Quit — Pigs Suffocate." "Ventilation System Failure Kills Pigs." Most producers have seen headlines like these. Similarly, salespeople for various products have used these headlines as opportunities to merchandise their version of safety equipment or a "safer" system.

Mechanically ventilated buildings have long been recognized as a safety risk during an electrical system failure. Non-mechanically ventilated, modified-open-front (MOF) buildings are generally viewed as less risky, since they are not dependent upon fans for air movement. However, others have argued that MOFs are risky due to possible cable or rope breakage.

Currently, construction of buildings for growing-finishing pigs includes flat ceilings, curtain sidewalls, totally slatted floors and a hybrid ventilation system. Most of these buildings use fans for cold and hot weather ventilation (tunnel system) and non-mechanical ventilation during mild and warm weather. These buildings also pose safety risks during an electrical system failure.

When dealing with a piece of electrical or mechanical equipment, the question is not *"if"* failure will occur, but *"when"*. Therefore, the goal should be to ensure — to the best of our ability — that the system will fail-safe, i.e., with minimum risk of loss or injury to people and animals. A major challenge in designing livestock production facilities is in developing a system with an acceptable risk-loss level.

Redundancy implies excess. Alternatively, redundancy means having a backup. For example, spare tires are redundant to the four tires on a car. The extra tire costs money. Nonetheless, most people carry a spare tire in their car or truck to minimize a flat tire's inconvenience. Redundancy is

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needed in ventilation systems to minimize the risk or magnitude of loss.

Examples of Ventilation System Failures

The following examples help to illustrate why a redundant ventilation system is needed.

Example one, a swine nursery was constructed with raised decks. Minimum ventilation was provided with a fan ducted to exhaust air from beneath the decks. During cold weather one night, a water line broke and filled the pit, closing off the fan duct. Result: Non-insured loss of 242 pigs.

Example two, a multi-room, mechanically ventilated nursery had several rooms equipped with gravity/static pressure-controlled box inlets. An electrical system failure during mild weather resulted in no fans operating and all inlets closing in three rooms. Result: Non-insured loss of over 300 pigs. No losses occurred in five other rooms with positive controlled inlets which remained open.

Example three, a two-room nursery facility used a single, centralized, computerized controller to operate ventilation equipment and monitor conditions in both rooms. A resistor ($2 item) failed in the master control board. Result: Non-insured loss of over 250 pigs.

Example four, a 500-head growing-finishing building (one of six on the site) was equipped with total slats, two-stage air-inflated curtain sidewalls, four pit fans and a sidewall fan. A centralized control system with multiple sensors and relays was used to operate and interconnect various ventilation system components. The air-inflated curtains were sold as a "hedge" against electrical system failure—if the power goes off, the inflating fan stops and the curtain opens. As designed, if both stages of both curtains close, the pit fans should turn on. The contact points in the pit fan control relay (a $10-$15 item) arced and became pitted, causing intermittent operation. During a cool July, the curtains closed, but the pit fans did not turn on. Result: Non-insurable loss of 257 market-weight pigs.

Example five, a mechanically ventilated growing-finishing building was equipped with 230-volt fans. Electrical service to the building was lost when one phase conductor of the underground electrical service burned off. (The aluminum conductor was less than four years old.) Evidence indicated significant; pre-failure corrosion. Result: Non-insured loss in excess of $40,000.

Options for Redundancy

Options for redundancy to reduce loss risk when the ventilation system fails include:

1. Standby power source—automatic or manual start
2. Alarm system
3. Combination of 115/230-volt fans
4. Multiple circuits to fans, curtain controllers, heater, etc.
5. Multiple curtain controllers per room
6. Thermostatically controlled fan independent of centralized master controller
7. Smoke alarms
8. Carbon monoxide alarms.

In two of the five examples above (no. 1 and 4) , most alarm systems would have been ineffective. The most cost-effective backup system, i.e., redundancy, depends upon the system being protected and failure against which protection is desired. No backup system is 100 percent reliable.

Regardless what system is installed, routine maintenance and inspection are required to help ensure the system will perform as expected when it is needed. Complacency makes a nonfunctional backup system worse than none at all.

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Nutrient Balance on Nebraska Livestock Confinement Systems

Rick Koelsch
Gary Lesoing[1]

Summary

Managing the environmental risk associated with livestock production is a significant challenge. The degree of imbalance between the amount of nutrient input and nutrient output for a livestock operation provides insight into the underlying causes of nutrient-related environmental challenges. A nitrogen and phosphorus balance was constructed for 33 Nebraska livestock operations (including 17 swine operations). On most farms, substantially more nitrogen entered the farm (through purchased feed, fertilizer, etc) than left it in the form of animals, crops and manure sold. Most farms also had an accumulation of phosphorus. Size of the operation and the degree of integration between livestock and a cropping operation provided only limited explanation of the variation in nutrient balance observed among the individual operations.

Introduction

Nitrogen (N) and phosphorus (P) losses to surface and groundwater are critical water-quality issues associated with livestock manure. In Nebraska, approximately 320,000,000 pounds of N and 230,000,000 pounds of P are excreted annually by livestock and poultry. A 1995 General Accounting

Table 1. Average characteristics and nutrient balance for 33 Nebraska livestock farms

	<250 animal units[1]	250-2500 animal units[1]	>2500 animal units[1]
	Farm Characteristics		
Number of livestock units	12	13	8
Animal units (1000 lb.):	154	668	7597
Cropped acres	578	932	1819
Crop acres per animal unit:	3.7	1.4	0.2
	Nitrogen Balance (tons/year)		
Inputs	38	102	922
Managed outputs	-26	-42	-405
Inventory change[2]	-3	-9	-2
N Imbalance ...tons/year	9	51	514
% of inputs	26%	55%	56%
	Phosphorus Balance (tons/year)		
Inputs	5.1	13.2	180
Managed outputs	-4.1	-8.7	-113
Inventory change[2]	-0.4	-1.4	-1
P Imbalance ...tons/years	0.6	3.1	66
% of inputs	14%	26%	37%

[1]One animal unit represents 1,000 lb of live bodyweight.
[2]Negative inventory change indicates an increase in inventory and a reduction in nutrient balance.

Office report to the United States Senate suggested manure was the source of 37 percent of all N and 65 percent of all P going into watersheds in the central states, including Nebraska.

An underlying cause of the environmental problems associated with livestock production is the accumulation of nutrients on livestock farms. A large fraction of the nutrients consumed by livestock does not leave the farm as meat, but remains on there in manure. An accumulation of nutrients on livestock operations would represent contributing factor to the industry's nutrient-related water-quality challenges.

The intent of this study was to define a whole farm nutrient balance on Nebraska livestock operations. The study also attempted to identify characteristics or management practices minimizing the accumulation of nutrients on farm.

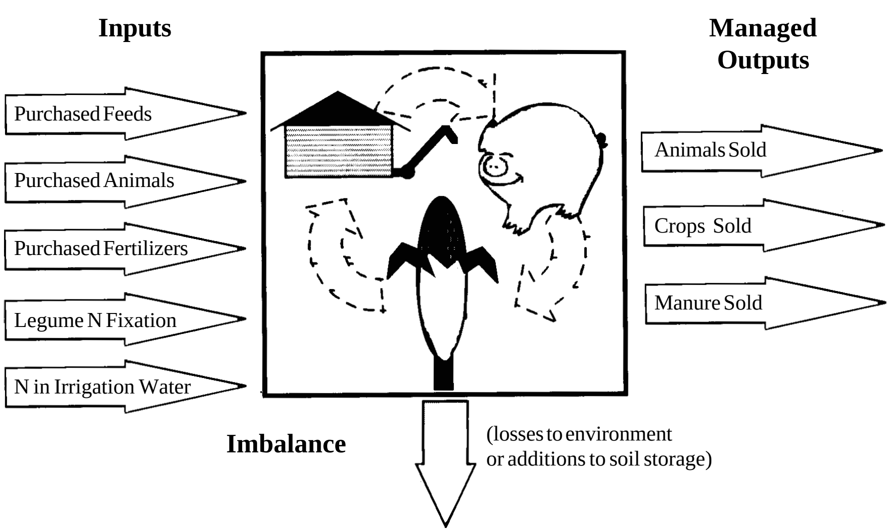

Figure 1. A whole farm nutrient balance considers multiple nutrient inputs and managed outputs for a livestock farm.

Procedure

An accounting of nutrient inputs (purchased feed, fertilizer, animals, biologically fixed nitrogen and nitrates in irrigation water) and managed nutrient outputs (animals, crops and other products moved off farm) was completed for 33 livestock operations (Figure 1). Changes in farm inventory of nutrient inputs and outputs were included in the analysis. The accounting period was for one year (1995 for six operations; 1996 for 27 operations). The degree of imbalance was estimated based upon the differences in inputs managed outputs, and inventory changes. The calculated imbalance in nutrients can either be lost to the environment (i.e., nitrate leaching to groundwater, or ammonia volatilization) or added to soil storage mechanisms (i.e., increasing soil phosphorus levels, which increase the risk of phosphorus in surface runoff).

Results and Discussion

The average nutrient balance for all 33 farms is summarized in three distinct size groupings in Table 1. The magnitude of nutrient inputs, managed outputs and imbalance increased with livestock operation size. The relative nutrient imbalance (percent of inputs) also increased with size of the operation and was more than two-fold greater for farms with more than 2,500 animal units as compared to farms with less than 250 animal units (see "percent of inputs" in Table 1).

Phosphorus balance provides a better indication as to when a sustainable nutrient balance has been achieved from a water quality perspective. The only environmental impact of a high P imbalance is on water quality. Nitrogen can be lost through volatilization (a relatively benign environmental loss) or to surface and groundwater (a more damaging environmental loss). Substantial losses of ammonia N by volatilization is often masked when a reasonable N balance is achieved. For this

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reason, the following comparisons will focus primarily on P balance.

The observed nutrient imbalance cannot be explained strictly by the size of the livestock operation (see Figure 2). Substantial variation in both N and P balance existed among individual farms. Although larger livestock units tend to have greater nutrient imbalances, farm size provides only a limited explanation for the observed variation. Some of the largest nutrient imbalances were observed for farms with 100 to 1,000 animal units.

A neutral or negative P balance was observed for several of the smaller livestock operations, indicating equal or greater managed outputs than inputs of P (Figure 2). These farms tended to have fewer livestock numbers and larger land bases. Farms with negative P balances were commonly removing more P from the soils as crops than was added as commercial fertilizer or manure. These farms were drawing upon soil phosphorus reserves during the year the nutrient balance was estimated.

Several larger livestock operations also had a relatively small P imbalance (see Figure 2). A closer review of data from three of those farms (cattle feedlots) indicates an active effort to move manure to neighboring crop producers. Marketing of manure nutrients increased the managed outputs of nutrients, contributing to an improved nutrient balance.

The degree of integration of crop and livestock enterprises is often considered an indicator of the relative potential for environmental problems (Figure 3). For the 33 participating farms, nutrient balance shows substantial variation when plotted against the density of livestock-to-land-base ratio. Lower P imbalances were more common for livestock operations with larger relative land bases. However, the three previously mentioned cattle feedlots, all with very limited land resources, were capable of achieving a reasonable balance in P inputs and managed outputs. The degree of integration of crop and livestock production provided only limited explanation

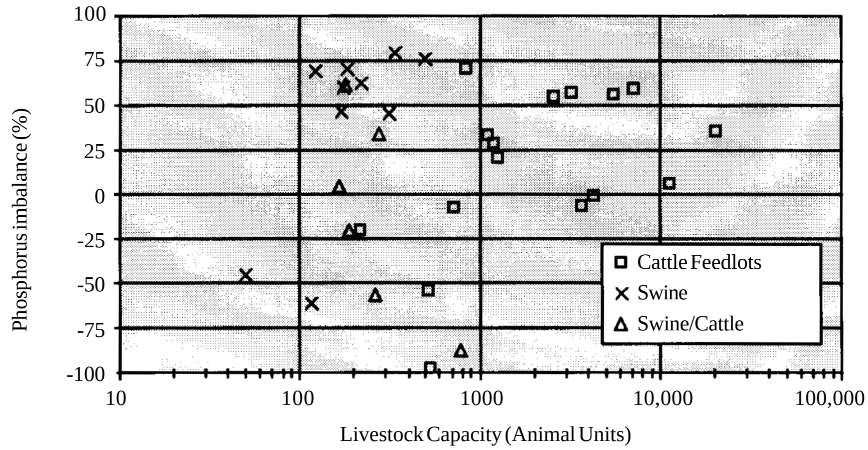

Figure 2. Phosphorus balance versus size for 33 Nebraska livestock operations.

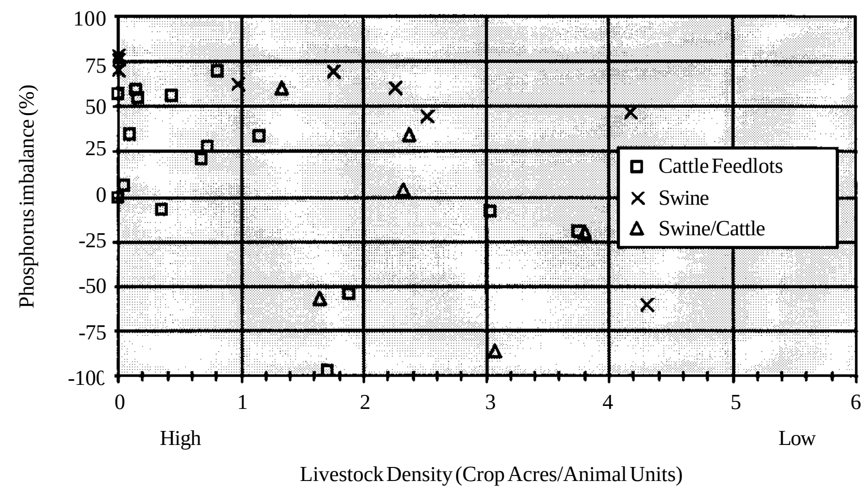

Figure 3. Phosphorus balance versus crop land to animal density for 33 Nebraska livestock farms.

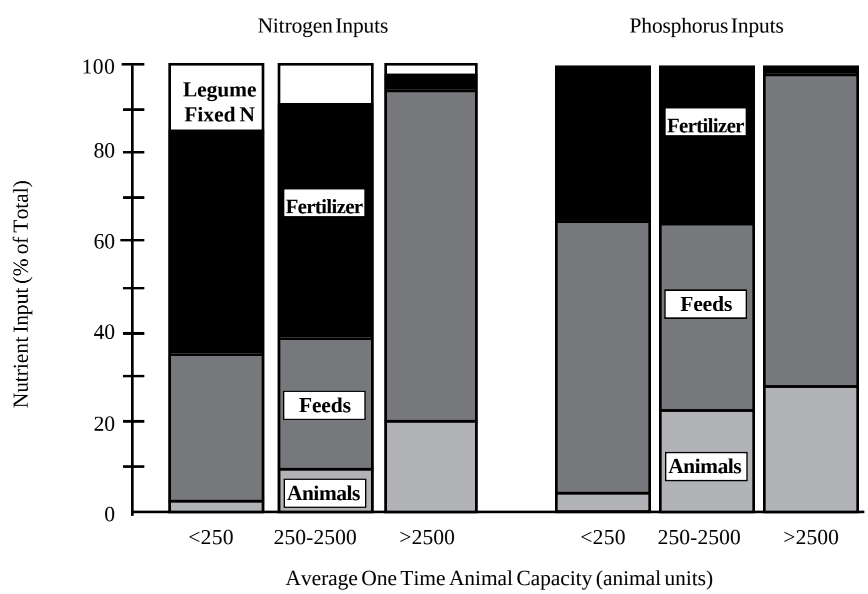

Figure 4. Relative sources of nitrogen and phosphorus inputs of different sized units.

for the variation observed.

The source of nutrient inputs to livestock operations is illustrated in Figure 4. Purchased animal feeds were a significant source of the N and P inputs. Nitrogen inputs as feed varied from 33 to 77 percent of total N inputs for farms with less than 250 animal units and more than 2,500 animal units, respectively. Phosphorus inputs as feed showed less variation, ranging from 62 to 71 percent of total inputs for the same livestock groupings. Livestock units < 250 animal units were predominantly swine operations. The addition of inorganic P to swine diets contributed to purchased animal feed being a primary source of P inputs.

Commercial fertilizer was the most significant N input for livestock operations with < 2,500 animal units. Fertilizer was also an important source of P input for these same farms. Commercial fertilizer was an insignificant nutrient input for the livestock operations with > 2,500 animal units (2 percent of nitrogen inputs and 1 percent of phosphorus inputs).

Industry Implications

This study highlights several critical implications relative to managing livestock operations in harmony with the environment.

1. Evaluating livestock systems nutrient balance from a whole-farm perspective provides a more complete picture of the driving forces behind nutrient-related environmental challenges. Accumulation of nutrients resulting from an imbalance of nutrient inputs and outputs is a problem for many, but not all, Nebraska livestock operations.

2. An assessment of environmental risk based strictly on factors such as livestock herd size or livestock to crop land density oversimplifies a complex issue. Both factors provided a very limited explanation of the variation in observed nutrient balance. Neither smaller-sized livestock operations or operations better integrated with crop production insured a "sustainable" nutrient balance resulted.

3. New strategies are needed for addressing the risk associated with nutrient accumulations on livestock operations. Management practices which stop nutrient leaks (i.e., feedlot runoff control) will not resolve nutrient related problems associated with livestock production. Nutrient management planning that focuses on improved utilization of manure nutrients to replace commercial fertilizers address only part of the nutrient inputs to most livestock operation. Future nutrient planning efforts should focus on improving whole-farm nutrient balances by:

- Reducing purchased feed nutrient inputs,
- Expanding managed outputs of nutrients by marketing manure nutrients to off-farm customers.

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The *Pig Pro* Decision, Networking, and Environmental Protection: The Public Policy Challenge*

J. David Aiken[1]

On August 29, 1997, the Nebraska Supreme Court issued its first decision interpreting the provisions of Initiative 300 (I300), Nebraska's family farm constitutional amendment. In its *Pig Pro* decision, a unanimous court ruled five Dawson county farmers who sought to form a non-profit cooperative corporation would violate article XII §12 of the Nebraska Constitution (I300). The decision means Nebraska farmers cannot network their operations and receive limited liability protection under I300.

The *Pig Pro* decision, handed down just when new, large swine facilities were proposed throughout the state, created an uproar. Many observers believe Nebraska swine producers do not produce enough hogs to keep existing Nebraska packing plants busy. These observers fear that if swine production is not increased, packers may leave Nebraska when their facilities need to be replaced. This would hurt the state's swine industry.

Although increasing swine production would address packer supply concerns, policy makers have at least two options to consider: (1) allow the increased swine production to come primarily from new swine facilities, some very large and developed by out-of-state interests or (2) encourage increased production from current Nebraska hog producers, including networking.

One way to allow Nebraska producers to compete with larger operations is for existing producers to network their operations along the line of the *Pig Pro* pig cooperative. Before I300 was adopted in 1982, "pig co-ops" were a common feature of the Nebraska swine industry. Neighbors would form a separate corporation for a farrowing operation. A manager would

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be hired to run the farrowing operation, and the pig co-op shareholders would receive pigs to feed to market weight on a rotating basis. This approach allowed pig co-op shareholders to concentrate on their grain production and feeding operations.

This practice was outlawed by I300 in 1982, although existing pig co-ops were "grandfathered." The Nebraska Supreme Court ruled in *Pig Pro* that new pig co-ops violate I300. Nonetheless, networking could help Nebraska swine producers supply the additional hogs needed to keep Nebraska packers fully supplied.

Interestingly, limited liability company (LLC) statutes may provide a way to legally authorize networking without amending I300. LLCs combine elements of corporations and partnerships into a new and distinct legal form of business organization. When I300 was adopted in 1982, LLCs were not well-known in Nebraska, and were legal only in Florida and Wyoming. LLCs were not authorized in Nebraska until 1993, with family farm LLCs first authorized the following year.

I300's corporate farming restrictions apply to (1) non-family farm or ranch corporations and (2) non-family farm or ranch limited partnerships. But I300 does not address LLCs, which in 1982 had not yet appeared on Nebraska's legal landscape. Only the Nebraska Supreme Court can officially determine whether LLCs are subject to I300 or not. But if LLCs are, in fact, not regulated by I300, the Unicameral could legally authorize LLCs to engage in agriculture on terms different from I300. Under this approach, the Unicameral could, for example, authorize neighbors to network livestock operations under a "small farm LLC", with LLC limited liability protection.

For example, small farm LLCs could be legislatively defined to require all LLC members to be current operating farmers. Similarly, the number of small farm LLC members could be limited to, for example, six. These types of limitations could prevent the small farm LLC from becoming a vehicle for investor involvement, the basic aim of I300, but still allow limited neighbor networking.

Small farm LLCs could lead to increased swine production in Nebraska to meet packer supply needs. But even without small farm LLCs, Nebraska swine production is still likely to increase if the proposed swine facilities around the state are developed. Some of the proposed facilities are large, prompting neighbor concerns about possible environmental effects. Several Nebraska counties are considering developing feedlot zoning regulations to control feedlot development.

Current Nebraska feedlot regulation policy is feedlot friendly. Because Nebraska is only beginning to see the rapid development of large swine facilities that has occurred in other states, our feedlot regulations have not been updated to deal with the special challenges posed by larger livestock facilities. That updating is likely to occur in 1998, and could consider both odor impacts and water quality protection (the current program focus).

Most (including most livestock producers) would agree livestock operations should be conducted in a way that respects neighbor's rights. The following changes could help accomplish that:

- large operations could be required to submit livestock waste management plans designed to minimize odors and water contamination
- large operations could be required to post cleanup bonds
- livestock operations would be required to follow best management practices (BMPs) in order to receive nuisance lawsuit protection under the Right to Farm law
- counties could be given the option to establish interim zoning regulations in order to develop a comprehensive plan and permanent county zoning regulation.

Let's look at these proposals in more detail.

Livestock waste management plans

Currently, the Nebraska Department of Environmental Quality (DEQ) requires livestock waste management plans for livestock operations requiring a DEQ water quality permit. However DEQ does not have staffing to monitor waste management plan compliance.

Changes to the current program could include (1) having sufficient acres for livestock waste disposal taking both nitrogen and phosphate loading rates into account, (2) requiring the larger facultative lagoons instead of smaller manure pits with 180 days storage in situations where odors are a concern and (3) requiring more stringent requirements to reduce nutrient leaching into groundwater. Natural Resource Districts, some of which already regulate manure application, could work with feedlot operators to help them meet manure application requirements.

Cleanup bonds

DEQ is authorized to require an environmental restoration (i.e. cleanup) bond as a condition for any permit DEQ issues. DEQ has not yet imposed cleanup bonds for feedlots. However, the special environmental impacts of large livestock operations may justify the imposition of a cleanup bonds as a feedlot permit condition.

Feedlot BMPs

Nebraska's first feedlot nuisance statute required livestock operators to use BMPs to qualify for nuisance lawsuit protection. This BMP requirement was not included in the subsequent Nebraska Right-to-Farm Act. However, most livestock operators would probably agree they should be subject to reasonable BMP requirements to show their willingness to be good neighbors.

In Ontario, where this approach is used, nuisance complaints are taken to an agricultural board instead of to court.

The board determines whether the appropriate BMPs are being used. If not, the board works with the producer to implement approved BMPs. This approach would focus the effort on implementing livestock BMPs instead of filing lawsuits to deal with livestock nuisance situations.

Interim county zoning regulations

Thirty-two Nebraska counties have adopted zoning regulations, authorizing them to regulate feedlot design, location and management. Other counties facing the development of new, large swine facilities are considering similar county zoning laws. However, zoning takes two years or more to implement, from development of a county comprehensive plan to the county board's adoption of the zoning regulation. The authority to establish temporary zoning regulations could allow needed time for counties to develop a permanent zoning regulation. Making interim county zoning authority optional would give each county the choice of whether or not to regulate feedlots under a temporary zoning regulation.

Large operations

What constitutes a "large operation" would be subject to considerable political debate, as would networking through new small farm LLCs. However, the failure (1) to enact adequate environmental safeguards for livestock production and (2) to encourage increased swine production through networking could hurt Nebraska's swine industry in the future. Hopefully these proposals will spark a healthy discussion which could have major implications for the future health of Nebraska's swine (and livestock) industry.

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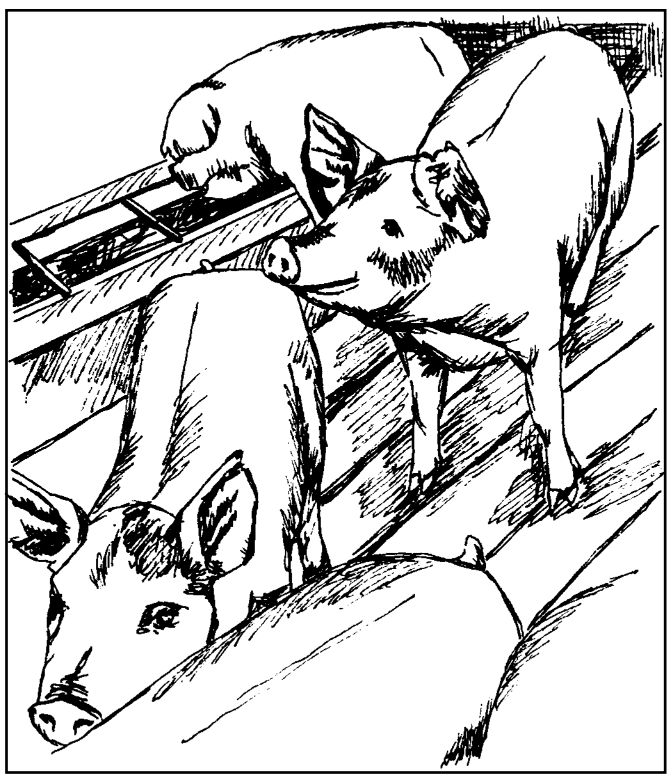
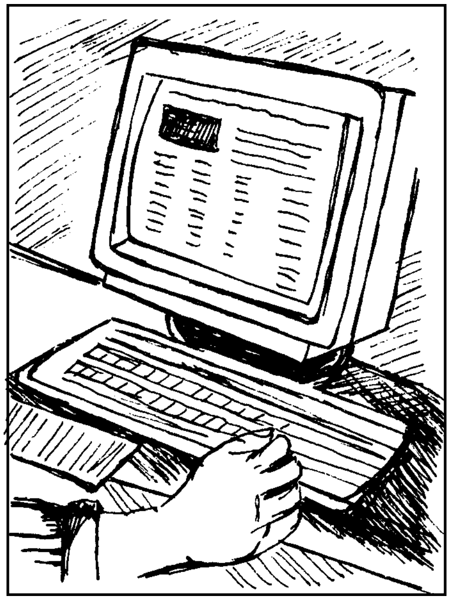


Explanation of Statistics Used in This Report

Pigs treated alike vary in performance, due to their different genetic makeup and to environmental effects we cannot completely control. When a group of pigs is randomly allotted to treatments it is nearly impossible to get an “equal” group of pigs on each treatment. The natural variability among pigs and the number of pigs per treatment determine the expected variation among treatment groups due to random sampling.

At the end of an experiment, the experimenter must decide whether observed treatment differences are due to “real” effects of the treatments or to random differences due to the sample of pigs assigned to each treatment. Statistics are a tool used to aid in this decision. They are used to calculate the probability that observed differences between treatments were caused by the luck of the draw when pigs were assigned to treatments. The lower this probability, the greater confidence we have that “real” treatment effects exist. In fact when this probability is less than .05 (denoted **$P < .05$** in the articles), there is less than a 5 percent chance (less than 1 in 20) that observed treatment differences were due to random sampling. The conclusion, then, is that the treatment effects are “real” and caused different performance for pigs on each treatment. Bear in mind, if the experimenter obtained this result in each of 100 experiments, 5 differences would be declared to be “real” when they were really due to chance. Sometimes, the probability value calculated from a statistical analysis is $P < .01$. With that figure, the chance that random



sampling caused observed treatment differences is less than 1 in 100. Evidence for real treatment differences, then, is very strong.

It is common to say differences are significant when $P < .05$ and highly significant when $P < .01$. However, P values can range anywhere between 0 and 1. Some researchers say there is a tendency for real treatment differences to exist when the value of P is between .05 and .10. “Tendency” is used because we are not as confident the differences are real. The chance that random sampling caused the observed differences is between 1 in 10 and 1 in 20.

Sometimes, researchers report standard errors of means **(SEM)** or standard errors **(SE)**. These are calculated from the measure of variability and the number of pigs in the treatment. A treatment mean may be given as $11 \pm .8$. The 11 is the mean and the .8 is the SEM. The SEM or SE is added and subtracted from the treatment mean to give a range. If the same treatments were applied to an unlimited number of animals the probability is .68 (1 = complete certainty) that their mean would be in this range. In the example the range is 10.2 to 11.8.

Some researchers report **linear (L)** and **quadratic (Q)** responses to treatments. These effects are tested when the experimenter used increasing increments of a factor as treatments. Examples are increasing amounts of dietary lysine or energy, or increasing ages or weights when measurements are made. The L and Q terms describe the shape of a line drawn to describe treatment means. A straight line is linear and a curved line is quadratic. For example, if finishing pigs were fed diets containing .6, .7 and .8 percent lysine gained 1.6, 1.8 and 2.0 lb/day, respectively we would describe the response to lysine as linear. In contrast, if the daily gains were 1.6, 1.8 and 1.8 lb/day the response to increasing dietary lysine would be quadratic. Probabilities for tests of these effects have the same interpretation as described above. Probabilities always measure the chance that random sampling caused the observed response. Therefore, if $P < .01$ for the Q effect was found, there is less than a 1 percent chance that random differences between pigs on the treatments caused the observed response.