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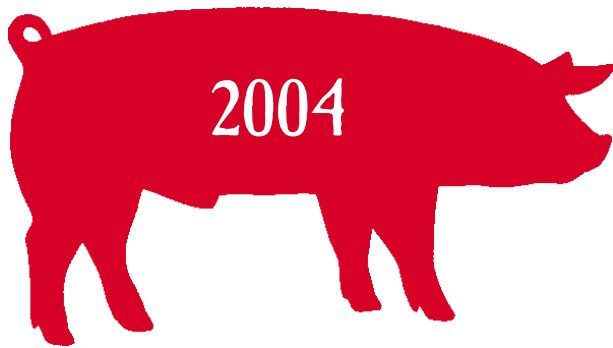


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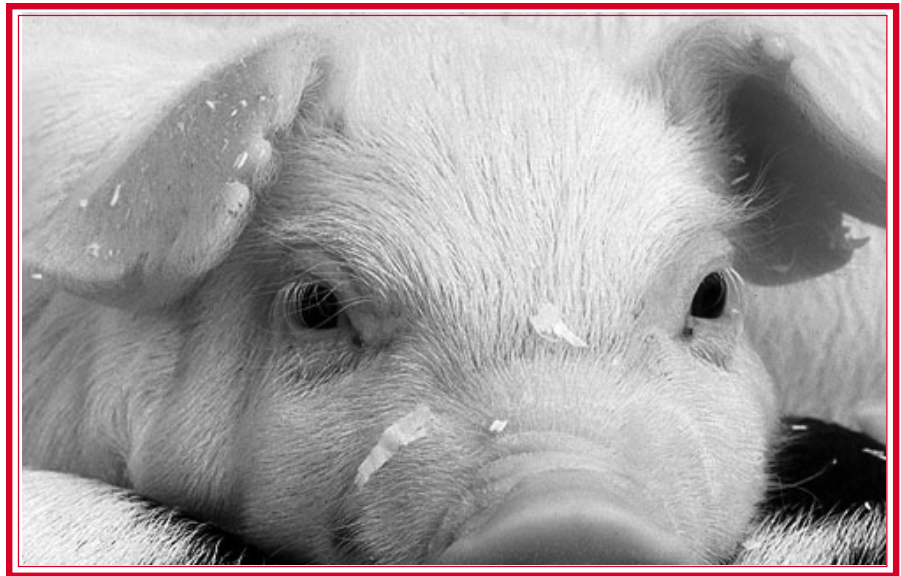
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NEBRASKA SWINE REPORT

- Nutrition
- Genetics
- Housing
- Public policy



Web site:

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

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Body Composition, Protein Deposition, and Efficiency of Lysine Utilization of Growing Pigs Fed Crystalline or Protein-Bound Lysine

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Summary and Implications

Two 4-week experiments were conducted to determine body composition and lysine utilization for protein deposition (PD) in barrows and gilts. Thirty-two growing pigs (16 barrows and 16 gilts; average initial body weight of 40.4 lb) were used in each experiment. Pigs were randomly allotted to one of seven dietary treatments. Four pigs (two barrows and two gilts) were killed at the start and the remaining pigs were killed at the end of the experiments to determine body composition. There were two replications per treatment in each experiment for a total of four replications. Dietary treatments consisted of a basal diet (0.55% lysine) and diets containing 0.65, 0.75, and 0.85% lysine that were achieved by adding lysine to the basal diet from either soybean meal (SBM) or L-lysine•HCl (crystalline). Body protein concentration was greater ($P < 0.01$) in pigs fed the 0.75% crystalline-supplemented diet than in pigs fed SBM at the same concentration. Gilts had greater ($P = 0.05$) body lysine concentration than barrows. Body PD and lysine deposition increased linearly with dietary lysine concentration ($P < 0.01$), but were not different between the two sources of lysine (SBM vs crystalline, respectively) at the same concentration. Barrows and gilts had similar PD and lysine deposition. Body fat concentration decreased ($P < 0.01$) as the dietary lysine concentration increased for both lysine sources; however, fat deposition was not affected by diet. Water deposition increased with dietary lysine concentration ($P = 0.05$).

Body ash content was similar in pigs fed crystalline or SBM-lysine. The results suggest that PD of growing pigs fed lysine from SBM is similar to that of pigs fed crystalline lysine. Pigs fed 0.75% or 0.85% total lysine (0.20% or 0.30% from SBM) had greater ($P \leq 0.05$) efficiency of lysine utilization than pigs fed crystalline-supplemented diets at the same concentration. Gilts utilized lysine from SBM more efficiently than barrows ($P < 0.05$) at the dietary lysine concentration of 0.75 and 0.85%. The results indicate no significant differences in PD of pigs fed supplemented diets from L-lysine•HCl and soybean meal. However, it appears that the efficiency of lysine utilization of gilts fed diets supplemented with SBM-bound lysine is greater than that of barrows. Supplementing low-protein diets with crystalline amino acids at adequate concentrations can offer environmental benefits towards reducing nitrogen excretion without affecting protein deposition.

Introduction

Supplementing swine diets with crystalline amino acids and replacing a portion of the dietary protein can reduce diet cost and the amount of nitrogen excreted. Because lysine is present in the least amount relative to its requirement (first-limiting amino acid) in swine diets, it is important to determine how this amino acid is absorbed and utilized for protein deposition.

Estimates of the efficiency of lysine utilization for muscle growth can vary depending on measurements used (e.g., nitrogen balance studies and/or comparative slaughter procedures). Also, the source of amino acid and its con-

centration in the diet affect its efficiency of utilization. Inefficient utilization of the first limiting amino acid in the diet for protein deposition may be a result of baseline degradation (oxidation) of amino acids. Thus, pigs do not use lysine for protein deposition with 100% efficiency, leading to variation in estimates of the efficiency of lysine utilization above maintenance for growing pigs. Estimates of the efficiency of lysine utilization for protein deposition in growing pigs range from approximately 32 to 44% up to 85 to 95%.

The 2003 Nebraska Swine Report documented a study demonstrating that when pigs were given ad libitum access to feed there were no differences in growth performance and carcass traits between pigs fed diets supplemented with L-lysine•HCl and pigs fed lysine from soybean meal (SBM). However, previous studies have reported the estimates of the efficiency of lysine utilization based on average daily gain and feed efficiency. The aforementioned approaches are not as specific as those based on carcass criteria because the former are sensitive to variations in gut fill. Thus, measuring protein deposition in the whole body represents a potentially more reliable indicator of the difference in the efficiency of lysine utilization between the sources of dietary lysine. Therefore, the objective of this study was to determine body composition and the efficiency of utilization of crystalline lysine as L-lysine•HCl relative to protein-bound lysine in SBM for body protein deposition in growing pigs.

(Continued on next page)



Procedures

Animals and Facilities

This study consisted of two experiments, each with 32 growing pigs (16 barrows and 16 gilts; average initial body weight of 40.4 lb) individually penned. Pigs were randomly allotted to one of seven dietary treatments. Four pigs (two barrows and two gilts) were killed at the start and the remaining pigs were killed at the end of the experiments to determine body composition. There were two replications per treatment in each experiment for a total of four replications.

Dietary Treatments

Diets were limiting only in lysine. For the 28-day experiment, pigs were allowed ad libitum access to one of the seven experimental diets and water. The seven diets used (Table 1) consisted of a basal diet (0.55% lysine) and diets containing 0.65, 0.75, and 0.85% total lysine that were achieved by adding lysine to the basal diet from either soybean meal (SBM) or L-lysine•HCl (crystalline). Tryptophan, methionine and threonine were added to the diets to meet the requirements for these amino acids in the basal diet and to the other diets to provide an amino acid pattern relative to lysine similar to the pattern in the basal diet.

Slaughter Procedures

The four pigs at the start and 28 pigs at the end of the experiment were killed by injecting an overdose of sodium pentobarbital. Gut contents (any remaining digesta) were removed and the whole body (including the gastrointestinal tract) weighed (empty body weight; EBW), and frozen at 0°F until further processing. The frozen empty body was ground using a commercial grinder with a 12.5-mm die. The ground body was thoroughly mixed to ensure homogeneity and a sample of approximately 9.0 lb was saved. Subsequently, each

Table 1. Composition of diets, as-fed basis.

Diets:	BASAL		CRYSTALLINE		SOYBEAN MEAL		
	0.55	0.65	0.75	0.85	0.65	0.75	0.85
Lysine, %:	0.55	0.65	0.75	0.85	0.65	0.75	0.85
Ingredient, %							
Corn	52.44	52.44	52.44	52.44	52.44	52.44	52.44
Cornstarch	13.00	12.61	12.23	11.85	9.64	6.33	2.97
Soybean meal, 46.5% CP	7.50	7.50	7.50	7.50	10.80	14.10	17.40
Sunflower meal	21.20	21.50	21.50	21.50	21.50	21.50	21.50
Tallow	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Dicalcium phosphate	2.20	2.20	2.20	2.20	2.10	1.95	1.85
Limestone	0.47	0.47	0.47	0.47	0.50	0.55	0.57
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin premix ^a	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Trace mineral premix ^b	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-Lysine•HCl	—	0.13	0.26	0.39	—	—	—
L-tryptophan	0.05	0.08	0.12	0.14	0.06	0.07	0.08
L-threonine	0.10	0.23	0.33	0.46	0.17	0.21	0.28
DL-methionine	0.07	0.19	0.29	0.39	0.14	0.20	0.25
Nutrient Composition^c							
Crude protein, %	14.80	14.90	15.00	15.40	16.30	17.80	19.30
Lysine, %	0.55	0.65	0.75	0.85	0.65	0.75	0.85
Calcium, %	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Phosphorus, %	0.60	0.60	0.60	0.60	0.60	0.60	0.60
ME ^d , Mcal/lb	1.38	1.37	1.36	1.35	1.37	1.36	1.35

^aSupplied per kilogram of diet: retinyl acetate, 5,500 IU; cholecalciferol, 550 IU; alpha-tocopheryl acetate, 30 IU; menadione, 4.4 mg; riboflavin, 11 mg; d-pantothenic acid, 22.05 mg; niacin, 30 mg; cyanocobalamin (vitamin B₁₂), 33.0 µg.

^bSupplied per kilogram of diet: Cu (as CuSO₄•5H₂O), 10.5 mg; I (as Ca(IO₃)•H₂O), 0.26 mg; Zn (as ZnO), 125 mg; Fe (as FeSO₄•H₂O), 125 mg; Mn (as MnO), 30 mg; Se (as Na₂SeO₃), 0.3 mg.

^cCalculated composition.

^dME = Metabolizable energy.

sample was ground three times using a smaller grinder with successively smaller dies (6.5-to-2-mm). Samples were mixed thoroughly by hand between each pass through the grinder. During the last mincing, frequent grab samples of approximately 100 g were taken at random, mixed thoroughly to obtain a total sample of approximately 500 g that was placed in a plastic bag and frozen at 0°F until laboratory analysis were conducted. Samples were analyzed in duplicate for dry matter (DM), ash, crude protein (CP), fat, and lysine.

Statistical Analyses and Calculations

Initial empty body weight (EBW) and chemical body composition of pigs slaughtered initially were used to estimate the initial EBW and body chemical composition of pigs slaughtered at the end of the experiment. Deposition rates of water, CP, lysine, fat and ash in the whole body were estimated as the difference between the total weight of chemical components at

the end and at the start of the experiment divided by the number of experimental days. The treatment design was 2 × 3 × 2 factorial + 2 (basal diet): 2 lysine sources (SBM and L-Lysine•HCl) × 3 lysine concentrations (0.65, 0.75, and 0.85%) × 2 sexes (barrows and gilts) + 2 (basal diets: 0.55% lysine barrows, 0.55% lysine gilts). Pig was considered the experimental unit. Data for concentration of body chemical components and deposition rates were analyzed as a complete randomized block design. The block for both analyses was considered as the combination between experiment and room (two experiments and two rooms). Linear contrasts were used to compare the seven dietary treatments. The contrasts were: basal diet vs the other diets and comparisons between lysine supplemented from crystalline lysine vs soybean meal at the lysine concentrations of 0.65%, 0.75%, and 0.85%, respectively. Linear and quadratic effects of dietary lysine concentration were tested. The



Table 2. Empty body weight (EBW), total lysine intake, whole body chemical composition and body deposition rates of pigs fed a basal or lysine supplemented diets.

Item	Diets ^a	CRYSTALLINE				SOYBEAN MEAL			SEM ^b	P-Value	
	Lysine, %	BASAL	0.65	0.75	0.85	0.65	0.75	0.85		Diet ^c	Basal vs others
Initial EBW, lb		38.13	38.85	38.60	37.22	37.22	39.10	37.25	1.25	0.86	0.95
Final EBW, lb		65.00	69.50	73.13	73.00	64.22	73.02	72.00	2.64	0.07	< 0.05
Total lysine intake, g/d		7.20	8.20	10.13	11.40	7.82	9.90	10.10	0.30	< 0.01	< 0.01
Body composition, %											
Protein ^e		15.10	15.22	15.28	16.10	15.51	16.04	15.72	0.18	< 0.01	< 0.01
Lysine		4.57	4.72	4.71	4.88	4.70	4.85	4.80	0.06	< 0.05	< 0.01
Fat ^f		15.88	15.71	14.24	12.93	15.08	14.70	12.71	0.49	< 0.01	< 0.01
Water ^d		65.00	65.00	66.27	66.24	65.00	62.45	64.34	1.12	0.27	0.90
Ash		2.54	2.30	2.27	2.25	2.47	2.39	2.30	0.08	0.06	< 0.05
Body deposition, g/d											
Protein ^f		63.16	73.19	84.24	96.71	67.68	90.87	89.82	4.51	< 0.01	< 0.01
Lysine		3.40	4.50	5.03	6.40	4.12	5.90	6.30	0.35	< 0.01	< 0.01
Fat		117.50	125.22	117.08	102.97	108.20	121.47	98.88	8.94	0.32	0.60
Water ^f		234.54	272.66	331.60	345.30	236.70	278.80	311.56	18.44	< 0.01	< 0.01
Ash		13.21	11.98	13.09	13.10	12.19	14.33	12.57	1.14	0.83	0.80

^aBASAL: lysine concentration provided by corn, soybean meal, and sunflower meal; CRYSTALLINE: BASAL diet supplemented with additional 0.10, 0.20 or 0.30% lysine from of L-lysine•HCl (78% lysine); SOYBEAN MEAL: BASAL diet supplemented with additional 0.10, 0.20 or 0.30% lysine from soybean meal.

^bStandard error of the mean.

^cSignificance of main effect.

^dSignificance of contrasts: CRYSTALLINE vs SOYBEAN MEAL at 0.75% Lys, (P < 0.05).

^eSignificance of contrasts: CRYSTALLINE vs SOYBEAN MEAL, at 0.75% Lys (P < 0.01).

^fLinear effect of lysine concentration (P < 0.01).

efficiency of lysine utilization for protein deposition (PD) was calculated for individual pigs considering the lysine deposition (g/d) in the whole body divided by total lysine intake above maintenance. It was assumed that the maintenance lysine requirement was 36 mg/kg BW^{0.75} (NRC, 1998).

Results

Whole Body Chemical Composition

Means and standard errors of EBW and chemical composition of pigs slaughtered at the end of the experiments are shown in Table 2. Body protein concentration was affected by dietary lysine concentration (P < 0.01). Pigs fed the basal diet had the lowest (P < 0.01) protein concentration in comparison with pigs fed the other diets. Protein concentration was greater (P < 0.01) in pigs fed the 0.75% crystalline-supplemented diet compared to pigs fed SBM at the same concentration (15.28 vs 16.04 %). However, pigs fed crystalline or SBM-supplemented diets had similar protein concentrations when

compared at 0.65 and 0.85% total dietary lysine. Pigs fed crystalline or SBM-supplemented diets had similar body lysine concentration. Body fat concentration decreased (P < 0.01) as the dietary lysine concentration increased similarly for both lysine sources as lysine concentration increased. Pigs fed the basal diets had the greatest fat concentration (P < 0.01). Dietary lysine did not affect (P > 0.10) body water concentration. However, water concentration was greater (P < 0.05) in pigs fed the crystalline-supplemented diets than pigs fed the SBM-supplemented diets (0.75% total lysine). There was a trend for ash concentration to be affected by dietary lysine concentration (P = 0.06). Pigs fed the basal diet had greater ash concentrations (P < 0.05). Whole body chemical components (protein, fat, ash, and water) were similar between barrows and gilts (Table 3). However, gilts had greater (P = 0.05) body lysine concentration than barrows. Total lysine intake increased with increasing dietary lysine concentration (P < 0.01).

Whole Body Deposition Rates

Tissue deposition rates of pigs slaughtered at the end of the experiments are presented in Table 2. Body PD and lysine deposition increased linearly as dietary lysine concentration increased (P < 0.01), but were not significantly different between the two sources of lysine when compared at the same concentration. Pigs fed the basal diet had the lowest PD (63.16 g/d; P < 0.01). Although barrows fed crystalline or SBM-supplemented diets had numerically greater PD than gilts, these differences were not significant. Thus, barrows and gilts had similar PD and lysine deposition regardless of lysine source (Table 4). Fat deposition was not affected by diet, sex, or lysine source. Water deposition increased linearly with dietary lysine concentration (P < 0.01) and was lowest (P < 0.01) in pigs fed the basal diet. Ash deposition was similar among dietary lysine concentrations and between sources of lysine. Water and ash deposition were similar between barrows and gilts (Table 4).

(Continued on next page)



Table 3. Whole body chemical composition of barrows and gilts fed a basal or lysine supplemented diets.

Item	Diets ^a	CRYSTALLINE				SOYBEAN MEAL			SEM ^b	P-Value	
	Lysine, %	BASAL	0.65	0.75	0.85	0.65	0.75	0.85		Sex ^c	Diet x Sex ^d
Body composition, %											
Water									0.16	0.18	0.35
Barrows		65.90	65.00	65.70	66.41	64.63	59.70	62.80			
Gilts		64.14	64.77	66.85	66.07	65.22	65.21	65.83			
Protein									0.26	0.66	0.58
Barrows		15.05	15.10	15.25	16.20	15.76	15.88	15.95			
Gilts		15.12	15.35	15.33	16.00	15.25	16.20	15.50			
Lysine									0.09	0.05	0.26
Barrows		4.61	4.75	4.50	4.80	4.65	4.80	4.78			
Gilts		4.53	4.70	4.88	5.00	4.74	4.92	4.82			
Fat									0.70	0.71	0.25
Barrows		15.23	15.63	14.80	12.70	15.70	15.44	12.25			
Gilts		16.55	15.60	13.70	13.20	14.45	13.93	13.20			
Ash									0.11	0.59	0.81
Barrows		2.45	2.30	2.35	2.26	2.40	2.35	2.30			
Gilts		2.63	2.31	2.20	2.24	2.54	2.42	2.23			

^aBASAL: lysine concentration provided by corn, soybean meal, and sunflower meal; CRYSTALLINE: BASAL diet supplemented with additional 0.10, 0.20 or 0.30% lysine from of L-lysine•HCl (78% lysine); SOYBEAN MEAL: BASAL diet supplemented with additional 0.10, 0.20 or 0.30% lysine from soybean meal.

^bStandard error of the mean.

^cSignificance of main effect.

^dSignificance of interaction.

Table 4. Whole-body deposition rates of barrows and gilts fed a basal or lysine supplemented diets.

Item	Diets ^a	CRYSTALLINE				SOYBEAN MEAL			SEM ^b	P-Value	
	Lysine, %	BASAL	0.65	0.75	0.85	0.65	0.75	0.85		Sex ^c	Diet x Sex ^d
Deposition rates, g/d											
Water									26.10	0.15	0.31
Barrows		194.10	280.37	314.10	337.40	259.50	263.74	290.82			
Gilts		275.01	264.96	349.10	353.14	213.81	293.84	332.30			
Protein									6.38	0.53	0.12
Barrows		52.81	75.27	82.61	97.77	77.17	94.37	93.18			
Gilts		73.51	71.11	85.88	95.64	58.19	87.36	86.46			
Lysine									0.49	0.17	0.57
Barrows		2.90	4.80	4.60	6.14	4.22	5.70	5.93			
Gilts		3.90	4.10	5.50	6.70	4.01	6.10	6.66			
Fat									12.64	0.25	0.21
Barrows		101.73	132.24	126.50	103.50	122.20	136.70	98.30			
Gilts		133.23	118.20	107.70	102.44	94.25	106.30	101.50			
Ash									1.62	0.26	0.43
Barrows		10.15	11.74	13.50	12.80	12.25	14.23	12.31			
Gilts		16.30	12.22	12.70	13.41	12.12	14.42	12.83			

^aBASAL: lysine concentration provided by corn, soybean meal, and sunflower meal; CRYSTALLINE: BASAL diet supplemented with additional 0.10, 0.20 or 0.30% lysine from of L-lysine•HCl (78% lysine); SOYBEAN MEAL: BASAL diet supplemented with additional 0.10, 0.20 or 0.30% lysine from soybean meal.

^bStandard error of the mean.

^cSignificance of main effect.

^dSignificance of interaction.

Efficiency of Lysine Utilization

Pigs fed 0.10% crystalline or SBM-supplemented diets (0.65% total lysine) utilized dietary lysine similarly (Figure 1). On the contrary, pigs fed 0.75% or 0.85% total lysine (0.20% or 0.30% added lysine from SBM) had greater ($P \leq 0.05$) efficiency of lysine utilization than pigs fed crystalline-supplemented diets at the same concentrations. Gilts utilized lysine from SBM more

efficiently than barrows ($P < 0.05$) at the dietary lysine concentrations of 0.75 and 0.85%.

Discussion

Body concentrations of protein, ash and water of pigs slaughtered at the end of the experiments were similar between pigs fed crystalline or SBM-supplemented diets. This indicates that pigs fed either source of dietary lysine will have

similar body composition. As expected, whole body protein concentration was lowest in pigs fed the basal diet because it was the diet most limiting in dietary lysine concentration. Although differences in water and protein concentrations were observed between pigs fed crystalline and SBM-bound lysine at 0.75% total lysine (0.20% added lysine), these differences were not consistent. Fat and ash concentra-

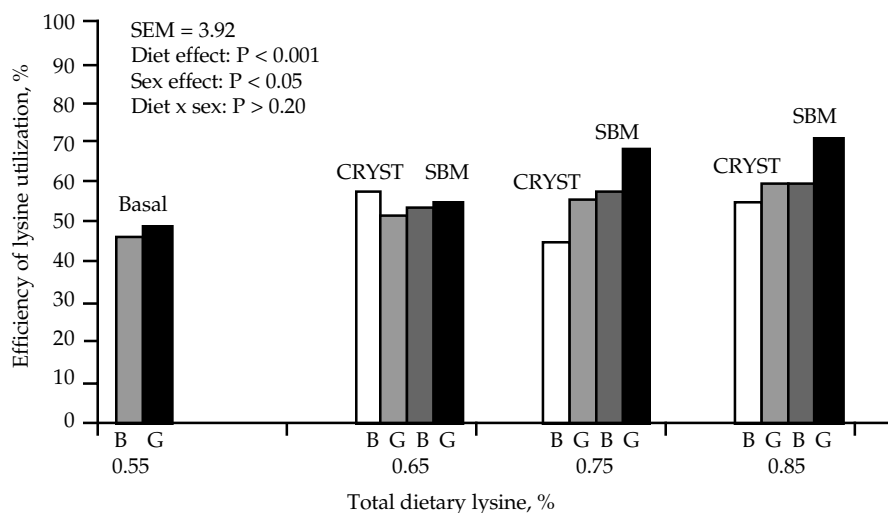


Figure 1. Efficiency of lysine utilization of barrows (B) and gilts (G) fed a basal or lysine supplemented diets. The efficiency of utilization for protein deposition (PD) of lysine intake above maintenance was calculated for individual pigs considering the lysine deposition (g/d) in the whole body divided by total lysine intake above maintenance. It was assumed that the maintenance lysine requirements were 36 mg/kg BW^{0.75} (NRC, 1998).

tions were also similar between dietary lysine sources.

Pigs fed crystalline or soybean meal-bound lysine had similar PD. The increased protein deposition rate observed as dietary lysine concentration increased in the crystalline-supplemented diets and the increasing lysine deposition in all supplemented diets imply that lysine was utilized with a constant efficiency over the range of limiting dietary lysine concentrations. Pigs fed the 0.30% SBM-supplemented diets (0.85% total lysine) had a decreased PD (compared to the 0.75% lysine group), which may be attributed to a concomitant decrease in body protein content. Although no significant differences in feed intake (Nebraska Swine Report 2003) were observed, the numerical decrease in feed intake possibly contributed to the reduced PD in these pigs.

The lack of difference between L-Lysine•HCl and SBM-bound lysine for PD is supported by previous studies. The data reported herein indicate that ad libitum access to feed provides a balanced supply of lysine at the sites of absorption and metabolism regardless of the dietary lysine source, thereby resulting in a similar utilization of L-lysine•HCl and SBM-bound lysine.

In the previous Nebraska Swine Report, it was reported that gilts had greater lean gain than barrows on a carcass basis. Therefore, a greater PD and lysine deposition in gilts were also expected. Contrary to these results, other studies have reported that barrows tended to have greater PD, which suggest that barrows had a greater capacity to deposit protein than gilts under ad libitum feeding conditions. However, in the aforementioned studies lysine was not limiting in the experimental diets. The similarity between barrows and gilts in the present study is explainable, because within the range of body weights studied, barrows and gilts had similar feed intakes. Differences observed in the efficiency of lysine utilization between pigs fed crystalline lysine and SBM-lysine at the two highest dietary lysine concentrations (0.75 and 0.85%) are related to the sex effect. Gilts were 5% more efficient utilizing lysine than barrows when 0.20 and 0.30% lysine was added from SBM. However, because of the similarity of both group of pigs at the lowest dietary lysine (0.65% total lysine), inferences about the differences between crystalline and SBM-lysine should be made cautiously.

Although significant differences were not observed, body fat

deposition rate decreased for pigs fed the crystalline supplemented diets from the lowest to the greatest dietary lysine supplementation (0.10% to 0.30%). On the contrary, in pigs fed the SBM-supplemented diets, there was an increase followed by a subsequent decrease in fat deposition. This could be explainable because at low lysine concentrations, PD is minimal and a greater proportion of energy is retained as fat. However, as dietary lysine concentration increased, PD increased and the energy stored as fat decreased.

Conclusions

The results obtained in the present study confirm that when pigs have ad libitum access to feed there are no differences in body composition and protein deposition attributed to diets supplemented with L-lysine•HCl and lysine from SBM. The increasing response in protein and lysine deposition of pigs fed the crystalline-supplemented diets indicates that the diets fed were limiting in lysine. Although pigs fed the SBM-supplemented diets had a slight decrease in the concentration and deposition rates of protein at the greatest amount of added lysine (0.30% Lys), these differences were not significant when compared to pigs fed diets supplemented with L-lysine•HCl. In addition, observed differences in the efficiency of lysine utilization (based on carcass lysine deposition) between lysine sources did not equate to significant differences in protein deposition. Therefore, supplementing low-protein diets with crystalline amino acids at adequate concentrations can offer environmental benefits toward reducing nitrogen excretion without affecting protein deposition.

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Dietary Antimicrobials in a Wean-to-Finish Facility

Michael C. Brumm¹

Summary and Implications

The routine use of growth-promoting antimicrobial feed additives is under increasing pressure worldwide. In response to this pressure, it is important that producers and their advisors understand under what circumstances these additives are likely to be effective or ineffective, allowing for improved decisions regarding their use. An experiment was conducted to examine the routine use of antimicrobial feed additives in a wean-to-finish facility. The weaned pigs used in this experiment were purchased from a source where grow-finish pigs were positive for PRRSV, circovirus-2 and Mycoplasma hyopneumoniae and had a previous history of Actinobacillus pleuropneumoniae (APP) related problems. Experimental treatments were no growth-promoting antimicrobials after the pre-starter diet versus continuous antimicrobial additions from weaning to slaughter and day of weaning replicated in a 2 x 2 factorial. At the end of the nursery phase eight weeks after weaning, pigs fed diets containing antimicrobials were heavier ($P < 0.01$) with less variation in weight ($P < 0.01$). There was no effect of treatment on feed conversion efficiency for this eight-week period. Pigs fed diets containing antimicrobials also had less severe diarrhea ($P < 0.01$) at six weeks post-weaning. During the grow-finish phase, diets meant to contain antimicrobials often assayed for lower antimicrobial content than intended. However, there were no mixing errors such that pigs meant to receive diets with no antimicrobials were offered

diets containing antimicrobials or vice versa. Pigs fed diets without antimicrobials grew faster ($P < 0.05$) with improved feed conversion ($P < 0.1$) during the grow-finish phase. Overall, there was no effect of dietary antimicrobial addition on pig performance, death loss, or carcass traits. In this experiment, while the weaned pigs were purchased from a source with known health challenges, the pigs remained very healthy, as evidenced by decreasing serum titers for APP and the lack of seroconversion for PRRSV. These results suggest that routine and continuous use of antimicrobial feed additives beyond the nursery stage in a wean-to-finish facility with high-health pigs should be evaluated on a case by case basis.

Introduction

Recently, the World Health Organization recommended that pork production systems world wide significantly reduce and eventually stop the use of growth-promoting antimicrobial feed additives. This follows the decision of the Danish government to ban their routine use, other than by veterinary prescription, and the recommendation of the European Union to ban growth-promoting antimicrobial use entirely. The basis for these recommendations is the belief that continuous additions of antimicrobials to swine diets contributes to the increasing public health problems associated with bacterial resistance to antimicrobials. In addition, many groups supporting a ban suggest that the response to growth-promoting antimicrobials in swine diets is much less than in previous

years. Therefore, the financial impact to the swine industry and the impact on pig health and welfare will be minimal upon their removal from the diet. However, recent evidence suggests the expected benefits to the antimicrobial ban have not been fully realized, resulting in an increased incidence of pig scours and death loss in Denmark, even though therapeutic use of antimicrobials has increased.

Growth-promoting antimicrobials have been approved for use in swine diets since the mid 1950s. Traditionally, pigs fed diets containing these compounds have had increased daily gain, improved feed efficiency, decreased variation in performance and improved health. A limit to applying the traditional data to today's production systems is that the health status of the pigs was often never verified. Scientists and regulators cannot answer the question posed by producers, advisors and critics — under what conditions can we expect a response and when is it logical to expect little or no response to antimicrobials?

The following experiment was conducted to investigate the effect of routine additions of growth promoting antimicrobials to swine diets in a wean-to-finish facility when pigs were purchased from a source herd with known health challenges.

Methods

The experiment was conducted at the University of Nebraska's Haskell Ag Lab Swine Research Unit



Table 1. Experimental diets.

Ingredient	Pre-starter	1	2	3	4	5	6	7	8
Corn		875	1050	1205	1230	1312	1384	1527	1680
Soybean meal, 46.5% CP		435	550	645	665	585	520	410	260
Fat		40	50	50	60	60	60	30	30
Dicalcium PO ₄ , 18.5%					15	13	6	3	0
Limestone					17	17	17	17	17
L-lysine					2	2	2	2	2
Akey Vit/TM premix ^a					4	4	4	4	4
Salt					6	6	6	6	6
Natuphos 600G ^b					1	1	1	1	1
Akey 2000 ^a	2000								
Akey Prestart 650 ^a		650							
Akey Start 350 ^a			350						
Akey Start 100 ^a				100					
Weight range, lb	11.5-13	13-18	18-25	25-40	40-60	60-90	90-135	135-190	190-mkt
Feed budget, lb/pig	2.1	6.7	10.0	23.7					
Lysine,%	1.64	1.44	1.37	1.31	1.21	1.10	1.01	0.87	0.67

^aAkey Inc, Lewisburg, OH

^bBASF Inc, Mt. Olive, NJ.

Table 2. Dietary antimicrobial additions for DRUG treatment.

Weight range, lb	Antimicrobial	Dietary addition, g/t
11.5-13	chlortetracycline (CTC)	400
	tiamulin	35
13-25	bacitracin methylene disalicylate (BMD)	250
	roxarsone	34.5
25-60	CTC	100
	sulfamethazine	100
	penicillin	50
60-market	BMD	30
75 (for 10 days)	CTC	400 (10 mg/lb of body weight/day)
135 (for 10 days)	CTC	560 (10 mg/lb of body weight/day)

near Concord, Neb. Pigs were housed in a double curtain, naturally ventilated, fully slatted confinement facility with 16 pens and daily fresh water, under slat flushing for manure removal. Each 8 ft x 14 ft pen contained 15 pigs and contained one two-hole wean-to-finish feeder and one wean-to-finish cup drinker.

The experimental treatments were:

- 1) Continuous dietary additions of growth promoting antimicrobials (Drug) vs none (Control)
- 2) Date of weaning

Diets were corn-soybean meal based and formulated according to the recommendations of Akey, Inc. (Lewisburg, OH) from weaning to 40 pounds bodyweight and according to the University of Nebraska recommendations for high lean gain pigs thereafter (Table 1). The pre-starter diet contained 400 g/t of chlortetracycline and 35 g/t of tiamulin for all pigs. Both the pre-starter and Diet 1 contained 2,310 ppm zinc as zinc oxide. All remaining diets were in meal form with or without the appropriate growth-promoting feed additive (Table 2). From weaning until 40 lb body

weight, pigs were fed according to the feed budget included in Table 1. From 40 lb body weight to slaughter, diets were switched on the week a pen achieved the target weight. Each delivery of feed was sampled and assayed for antimicrobial content by Alphaforma Inc.

Two-hundred and forty newly weaned pigs (DK33 dam x Danbred NA sire; 15-21 days old) were purchased from a herd where grow-finish pigs were positive for PRRSV, circovirus-2 and *Mycoplasma hyopneumoniae*. The source herd also had a previous history of *Actinobacillus pleuropneumoniae* (APP).

On the day of weaning, pigs were transported to the research facility, eartagged, weighed and ranked within sex by weight. Every weight outcome group of eight pigs within sex was randomly assigned to pens. Pigs were weaned on Sept. 16 and Sept. 18, with 120 head delivered each day.

Approximately 2.5 weeks post-weaning, all pigs received a commercial electrolyte and citric acid in the water for five days as a preventative treatment for gut edema caused by beta-hemolytic *E. coli*. Pigs were vaccinated via the water for erysipelas at 8 weeks post-weaning.

(Continued on next page)



Table 3. Effect of experimental treatments on pig performance.

Item	Treatments				SE	P Values	
	Dietary Drug		Wean Date			Drug	Wean
	No	Yes	9/16/02	9/18/02			
No. pens	8	8	8	8			
Pig weight, lb							
Wean	11.4	11.4	11.8	10.9	<0.1	NS ^a	<0.01
Day 57 ^b	63.9	69.4	70.8	62.4	0.8	<0.01	0.01
Final ^c	257.7	255.2	261.9	251.0	2.6	NS	0.05
Coefficient of variation of pig weight within a pen, %							
Wean	20.3	22.1	21.9	20.6	0.8	NS	NS
Day 57 ^b	18.8	14.8	14.4	19.2	0.8	<0.01	<0.01
Final ^c	10.1	9.3	9.5	10.0	0.8	NS	NS
Average daily gain, lb							
Wean-day 57 ^a	0.94	1.03	1.04	0.94	0.01	<0.01	<0.01
Day 57 ^b -final	1.85	1.77	1.82	1.80	0.02	<0.05	NS
Overall	1.53	1.52	1.54	1.50	0.02	NS	<0.1
Average daily feed, lb							
Wean-day 57 ^b	1.57	1.70	1.71	1.56	0.02	<0.01	<0.01
Day 57 ^b -final	5.45	5.32	5.40	5.38	0.07	NS	NS
Overall	4.09	4.05	4.10	4.03	0.05	NS	NS
Feed:gain							
Wean-day 57 ^b	1.67	1.65	1.66	1.67	0.02	NS	NS
Day 57 ^b -final	2.96	3.01	2.97	2.99	0.02	<0.01	NS
Overall	2.67	2.67	2.66	2.69	0.02	NS	NS
IBP, Inc.							
Backfat, in.	0.80	0.83	0.81	0.83	0.02	NS	NS
Loin depth, in.	2.74	2.75	2.75	2.74	0.02	NS	NS
% lean	54.80	54.60	54.80	54.70	0.01	NS	NS
Carcass value, \$/cwt	48.31	48.13	48.31	48.13	0.28	NS	NS
Hot carcass wt., lb	196.7	193.6	198.8	191.4	1.6	NS	<0.01

^aNS = not significant ($P > 0.1$).

^bDay 58 and day 56 for pigs weaned on 9/16 and 9/18, respectively.

^cDay 163 and day 161 for pigs weaned on 9/16 and 9/18, respectively.

At weaning, one barrow and one gilt per pen were randomly selected, and these pigs were bled via vena puncture on week 0, 4, 8, 12, 16, 20 and before slaughter. Serum was harvested and frozen for subsequent serology profiling.

All pigs that died during the experiment were examined for cause of death by a consulting veterinarian. Pen size was not adjusted in the event of pig death. A record was maintained of any injectable antibiotic use for treatment of lameness, obvious respiratory distress, etc. No water-soluble antimicrobials were administered to either treatment group.

All pigs were slaughtered on the same day at IBP Inc at Madison, Neb. Pigs were identified with tattoo by sex within pen and carcass data was collected by IBP employees.

Results were analyzed as a complete random design using a 2 × 2 factorial arrangement of treatments using the GLM procedure of SAS with the pen of pigs as the experimental unit. The model included weaning date, use of feed additive and the interaction of these main effects.

Results and Discussion

On Oct. 30 (days 42 and 44 post-weaning), many pens of pigs were noted to have diarrhea. The pens were scored for severity of diarrhea, by a veterinarian without knowledge of the dietary treatment assignments, using a 1 to 3 scale with 1 being normal feces and 3 being severe diarrhea. The average scores were 1.25 for pens with diets containing feed additives (Drug) and 1.88 for Control pens ($P < 0.01$). No samples were collected for submission to a veterinary diagnostic laboratory and within two weeks there were no differences noted among the pens for diarrhea.



Three pigs died during the experiment. Death loss could not be related to either of the experimental treatments. Use of injectable and antimicrobials to treat individual pigs was minimal and also not related to the experimental treatments.

At the end of the experiment, frozen serum samples from the bleedings on weeks 0, 12 and just before slaughter were submitted to the University of Nebraska Veterinary Diagnostic Laboratory. All samples were negative for PRRSV other than three samples thought to be false positives. Several pigs were positive (complement fixation test) for APP at weaning. However, the titers declined over time, suggesting no active infection. Thus, the pigs maintained a relatively high health status during the experiment, in spite of the attempt to identify a source of pigs with health challenges often encountered in production systems.

Pig performance is presented in Table 3. There were no interactions between weaning day and dietary treatments ($P > 0.1$) except for coefficient of variation (CV) for pig weight within the pen on day 57. Day 57 in the table is day 58 for pigs weaned on Sept. 16 and day 56 for pigs weaned on Sept. 18. The interaction for CV on day 57 ($P < 0.05$) is due to the amount of the response to the experimental treatments, and not due to a difference in response. For pigs weaned on Sept. 16, the CV for within pen weight on day 57 was 14.8% and 14.0% and for pigs weaned on Sept. 18, the CV was 22.8% and 15.5%, for Control and Drug treatments, respectively.

For the first eight weeks post-weaning, pigs given diets that included growth promoting feed additives grew faster (1.03 vs 0.94 lb/d; $P < 0.01$) with no difference in feed conversion. Because they grew

faster, pigs given diets that included growth promoting feed additives were 5.5 pounds heavier (69.4 vs 63.9 lb; $P < 0.01$) and had less weight variation within the pen (day 57 CV 14.8% vs 18.8%; $P < 0.01$) on day 57 of the trial.

However, during the period from day 57 to final, pigs given diets containing no growth promoting additives grew faster (1.85 vs 1.77 lb/d; $P < 0.05$) and were slightly more efficient (2.96 vs 3.01 lb/lb; $P < 0.1$). Much of this difference in performance occurred during the two-week period from day 57 to day 71. During this period, pigs given diets with no growth promoting feed additive grew faster (1.87 vs 1.74 lb/d; $P < 0.05$) and were more efficient (2.08 vs 2.25; $P < 0.05$). There was no effect of dietary antimicrobial treatment on any carcass parameter. The heavier hot carcass weight for pigs weaned on Sept. 16 vs Sept. 18 is a reflection of the heavier weaning weight ($P < 0.01$), faster overall daily gain ($P < 0.1$) and heavier final weight ($P < 0.05$). Date of weaning had no effect ($P > 0.1$) on any other carcass parameter.

Possibilities for why the improvement in performance during the nursery phase was not maintained during the grow-finish phase for pigs fed diets containing antimicrobials include the health status of the pigs and possible mixing errors at the feedmill. In spite of identifying a source of pigs from a herd with known health challenges in growing-finishing pigs, the pigs used in this experiment remained very healthy, possibly due to the smaller number of pigs in the facility. There were 240 pigs in the research facility, while in commercial facilities it is common to have 500-1,000 or more pigs per air space. The source herd often had this many pigs in various facilities.

The research diets were mixed at a commercial mill and every delivery was assayed for antimicrobial additions. All of the control diets were negative for antimicrobial additions. The U.S. Food and Drug Administration (FDA) allows assays for bacitracin methylene disalicylate (BMD) to vary $\pm 30\%$, or feeds with 30 gm/ton additions to assay at 21 to 39 gm/ton and still be considered as meeting the label claim for 30 g/t additions. All assays were less than 30 g/t, with several less than 19 g/ton. Thus, the lack of response during the grow-finish phase may have been due in part to the lower than intended level of addition of BMD. Assays for the other antimicrobial additions to the diets were generally within US-FDA accepted ranges.

Conclusions

In this experiment, the use of antimicrobial growth promoting feed additives improved daily gain, reduced within pen weight variation for the first eight weeks post-weaning, and reduced the severity of diarrhea. However, during the grow-finish phase there was no overall effect of antimicrobials in the diet. These data suggest that the use of antimicrobial growth promoting feed additives remains an effective management tool during the nursery phase of production. However, there was no response during the grow-finish phase, possibly due to the very high health status of the pigs or lower than intended level of antimicrobial additions.

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Update on Omega-3 Fatty Acids and Litter Size in Swine

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Summary and Implications

A literature review was conducted to examine the role that dietary omega-3 fatty acids may have in improving litter size in swine. Omega-3 fatty acids are not normally present to any great extent in practical swine diets, but they are increasingly believed to be important in human and pet health. In all but one of the studies reviewed the number of pigs born alive improved (0.2 to 0.7 pigs/litter) when sows were provided diets that contained more omega-3 fatty acids. In all the studies that reported litter size at weaning, positive responses were observed (0.3 to 1.3 pigs/litter) with omega-3 fatty acid supplementation. The response is highly variable and probably due to the source, level and timing of feeding the omega-3 fatty acids. It seems possible for producers to improve the profitability of pork production by supplementing sow diets with omega-3 fatty acids.

Introduction

The role of fat and oil in sow diets received considerable attention by researchers 20 to 30 years ago. Interest was centered on improving piglet preweaning survival and reducing the nutrient drain experienced by lactating sows. Those investigations showed that supplemental fat provided to the sow pre-farrowing generally improves preweaning survival, but its role in reducing nutrient drain during lactation is less meaningful. Fat and oil have basically served as sources of energy in swine diets.

Fats and oils consist of fatty acids. Each fat or oil source has a unique fatty acid profile that distinguishes one fat or oil source from

another. Nutritionists have been examining the health benefits of specific fatty acids, especially omega-3 fatty acids, in pet and human health for several years. The omega-3 fatty acids are linolenic; eicosapentaenoic (EPA); and docosahexaenoic, (DHA). Linseed (flaxseed) is the most abundant source of linolenic acid; canola oil is the next best source, while negligible amounts are found in the other sources of fats and oils. In contrast, fish oils are the only sources of the other two omega-3 fatty acids (EPA and DHA).

The role that omega-3 fatty acids may have in swine reproduction has been investigated. A review of those research results were presented in the 2003 Nebraska Swine Report (available at <http://ianrwww.unl.edu/pubs/swine/pigpdf.htm>). Since that review was prepared research results from two experiments have been published. Therefore, a re-evaluation of the role of omega-3 fatty acids in sows diets is warranted.

New Research Results

Researchers at United Feeds Inc. fed 338 primiparous and multiparous sows either a corn-soybean control diet or the control diet top-dressed with Fertilium™, a protected omega-3 fatty acid source. Fertilium™ was top-dressed at the rate of 85 g/day beginning 5 ± 2 days before farrowing through to day 7 postweaning for a total of 35 days. Sows were mated at first estrus after weaning. All sows received a common diet throughout gestation until subsequent farrowing. Sows that received Fertilium™ farrowed significantly more total (11.6 vs 11.0) and live pigs (10.8 vs 10.3) than control sows.

University of Manitoba and Minnesota researchers fed 243 multiparous sows either a barley/wheat-canola meal control diet or the control diet with 5% flaxseeds (rich source of linolenic acid) from breeding to weaning. Litter size born alive was not significantly improved by feeding flaxseeds; however, sows fed flaxseeds weaned more pigs than those fed the control diet (10.4 vs 9.1). In addition, pigs from sows fed flaxseeds were significantly heavier at weaning than those from control sows (10.6 vs 9.5 lb).

Litter Size Summary

A summary of research results published to date on the effect of omega-3 fatty acids on litter size is presented in Table 1. In all but one of the studies reviewed, the number of pigs born alive improved (0.2 to 0.7 pigs/litter) when sows were provided diets that contained more omega-3 fatty acids. In all the studies that reported litter size at weaning, positive responses were observed (0.3 to 1.3 pigs/litter) with omega-3 fatty acid supplementation.

Previous research suggests that pigs cannot make sufficient quantities of EPA and DHA from linolenic acid to elicit certain biological effects. Therefore, to maximize benefits that EPA and DHA may impart on litter size, it would seem necessary to add them preformed to the diet. In practical feeding situations, that can be accomplished by adding fish oil or fish or marine products to the diet. However, the response observed from feeding flaxseed (study 5) suggests that linolenic acid may influence reproduction too and/or there is sufficient synthesis of EPA and DHA from linolenic acid to elicit a litter size response.



Table 1. A summary of the effect of providing additional omega-3 fatty acids in sow diets on litter size born alive.

Study ^a	Omega fatty acid source	Dietary level or amount	Feeding period	No. of litters	Live pigs born/litter			Pigs weaned/litter			Comments
					- ^b	+ ^b	Change	- ^b	+ ^b	Change	
1	Fishmeal	5.00%	Two reproductive cycles	NA ^c	10.4	10.9	+0.5	8.3	9.4	+1.1	First parity data; 200 gilts started experiment
1	Fishmeal	5.00%	Two reproductive cycles	NA	10.7	10.9	+0.2	9.3	9.6	+0.3	Second parity data
2	Salmon oil	1.75%	3 d post service to weaning	NA	11.9	11.7	-0.2	10.5	10.6	+0.1	216 sows started experiment; treatment and parity possibly confounded
3	Salmon oil	1.65%	3 d post service to weaning	198	11.6	11.8	+0.2	10.2	10.6	+0.4	
4	Fertilium TM	85 g/d	d 109 gestation to d 7 postweaning	338	10.3	10.8	+0.5	NA	NA		P < 0.05
5	Flaxseeds	5.00%	d 1 post breeding to weaning	243	10.8	11.5	+0.7	9.1	10.4	+1.3	P > 0.05 for live pigs; P < 0.05 for weaned pigs

^a1 = Edwards and Pike, 1997; 2 = Cordoba et al., 2000; 3 = Rooke et al., 2001; 4 = Webel et al., 2003; 5 = Baidoo et al., 2003.

^bWithout (-) or with (+) added omega-3 fatty acids in the diet.

^cNot available.

Table 2. Increase needed in the number of pigs weaned/litter to offset extra sow feed ingredient expense due to providing omega-3 fatty acids.^a

Extra sow feed expense, \$/sow/year	Value of a pig at weaning, \$/pig			
	20	25	30	35
5	0.11	0.09	0.08	0.06
10	0.23	0.18	0.15	0.13
15	0.34	0.27	0.23	0.19
20	0.45	0.36	0.30	0.26
25	0.57	0.45	0.38	0.32

^aAssumes 2.2 litters/sow/year.

Economics

An economic analysis was performed to estimate the extent that litter size weaned needs to improve to offset the extra sow feed ingredient expense incurred from adding omega-3 fatty acids to the diet (Table 2). Adding 5% fishmeal or flaxseed to gestation and lactation diets will increase annual sow feed expense by about \$20 to 25/sow. To offset this extra expense, a producer would need to be reasonably sure that litter size at weaning would improve by 0.26 to 0.57 pigs/litter depending on pig value. Results so far with fishmeal and flaxseed show a litter

size improvement at weaning of 0.3 to 1.3 pigs/litter (Table 1). In contrast, feeding FertiliumTM increases annual sow feed expense by about \$10 and requires a litter size improvement at weaning between 0.13 and 0.23 pigs to breakeven. FertiliumTM has improved litter size born alive by 0.5 pigs/litter according to one report. While it is not certain that the extra pigs born alive from feeding FertiliumTM would survive to weaning, it is reasonable to expect they would. According a previous literature review on omega-3 fatty acids in swine (2003 Nebraska Swine Report, page 30), it appears piglet

preweaning survival may be improved by omega-3 fatty acid supplementation provided the sows are allowed to farrow naturally (without induction).

Conclusion

Increasing the omega-3 fatty acid content of sow diets appears to improve litter size, although the response is highly variable. The variable response appears to be due to the source, level and timing of feeding omega-3 fatty acids. It seems possible for producers to improve the profitability of pork production by supplementing sow diets with omega-3 fatty acids. However, producers are advised to use some caution before implementing this technology, because of its cost and lack of testing in multiple production systems.

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Effects of Sow Dietary Glutamine Supplementation on Sow and Litter Performance, Subsequent Weanling Pig Performance and Intestinal Development After an Immune Challenge

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Summary and Implications

Sixteen sows were randomly assigned to two treatments: CON: Control corn-soybean meal diet; GLN: Corn-soybean meal diet + 2.5% crystalline glutamine. No differences ($P > 0.10$) between treatments were observed for sow weight loss, sow feed intake, or litter weight gain. Sow plasma glutamine concentration tended to be increased on days 7 and 21 ($P < 0.13$) in sows fed GLN. Milk glutamine concentration was increased ($P < 0.08$) on days 7 and 21 of lactation. However, suckling pig plasma glutamine concentration was not altered ($P > 0.38$) on day 21 by glutamine enriched milk consumption. On day 21, pigs were weaned to a common starter diet, sow treatment structure was maintained, and two additional treatments were imposed on weanling pigs and arranged in a 2×2 factorial: SAL: Saline injection on days 1 and 3; Lipopolysaccharide (LPS) $91 \mu\text{g} \cdot \text{lb BW}^{-1}$ injection on days 1 and 3. Lipopolysaccharide injection on days 1 and 3 reduced ($P < 0.05$) ADG during days 0 to 3, 3 to 7, and 7 to 14. Daily feed intake was reduced ($P < 0.005$) during days 0 to 3, 3 to 7, 7 to 14, and 14 to 21 by LPS injection. However, LPS increased ADG/ADFI during days 3 to 7 ($P < 0.0001$) and days 7 to 14 ($P < 0.02$). Progeny of sows fed CON diet gained 0.14 lb/d ($P < 0.03$) more weight during days 3 to 7, and consumed 0.33 lb/d more feed ($P < 0.09$)

during days 7 to 14 versus progeny of GLN-fed sows. Small intestine length measured on day 3 was not affected ($P > 0.23$) by sow diet or injection type. Pigs injected with LPS had reduced ($P < 0.01$) small intestine empty weight. Progeny from sows that consumed CON had 10% greater empty weight on day 7 compared to progeny from sows fed GLN. Pigs injected with LPS had reduced ($P < 0.01$) small intestine weights on day 7 compared to pigs injected with SAL. Lipopolysaccharide challenge reduced ($P < 0.01$) duodenum villus height. However, progeny of sows that consumed GLN had 12% greater ($P < 0.05$) villus height on day 3 compared to progeny of sows fed CON. Duodenum villus height on day 7 was similar in progeny from sows fed GLN and injected with SAL; whereas, progeny from sows fed GLN injected with SAL had reduced villus height (Diet \times LPS, $P < 0.05$). Collectively, these data suggest that dietary glutamine increases sow milk glutamine concentration, but does not positively influence progeny growth performance during lactation or immediately following weaning during an immune challenge.

Introduction

Previous research conducted at this station (see Kitt et al., Nebraska Swine Report 2003) suggested that glutamine may be a dietary essential amino acid during an immune challenge immediately following weaning. However, currently no assay is available to quantify glutamine in feedstuffs; additionally, crystalline glutamine is not

economically practical to include in weanling pig diets. One method to heighten piglet glutamine intake is via increased piglet glutamine composition of sow milk. Therefore, we proposed to investigate whether increased sow glutamine intake alters milk glutamine composition and subsequently affects growth performance and intestinal characteristics of immune-challenged weanling pigs.

Procedures

Sow and Litters.

On approximately day 106 of gestation, 16 sows were transported from the University of Nebraska Agricultural Research Division Swine Farm to the Animal Science Complex. Upon arrival, sows were weighed and randomly allotted to treatments; whereby, treatments were initiated on the day of parturition. Treatments were: 1) Corn-soybean meal (CON), or 2) Corn-soybean meal + 2.5% L-glutamine (GLN), where L-glutamine replaced corn in the diet (Table 1). Until parturition, sows were fed 6.0 lb/d of a standard 14% CP corn-soybean meal gestation diet. All sows were induced to farrow via intramuscular injection of 10 mg prostaglandin $F_2\alpha$ (In-Synch, Pro Labs, St. Joseph, MO) on day 112 of gestation. All sows farrowed within 25 h of the first sow farrowed. Sows were weighed on days -3, 7, 14 and 21 relative to farrowing and litters were weighed on days 0, 7, 14 and 21. By day 1 post-farrowing, litters were standard-



Table 1. Ingredient and calculated nutrient composition of sow diets (as-fed basis).

Ingredients, %	Treatment ^a	
	CON	GLN
Corn	63.35	60.85
Soybean meal, 46.5% CP	30.00	30.00
Dicalcium phosphate	2.65	2.65
Bleachable tallow	2.50	2.50
Limestone	0.60	0.60
Salt	0.50	0.50
Breeding vitamin premix ^b	0.25	0.25
Trace mineral premix ^c	0.15	0.15
L-Glutamine	2.50	—
Calculated nutrient composition		
Lysine, %	1.00	1.00
ME, kcal/lb	1,534	1,495
Crude fat, %	5.86	5.76
Crude fiber, %	2.26	2.21
Ca, %	0.96	0.96
P, %	0.88	0.87
P, avail. %	0.55	0.55
Analyzed nutrient composition		
CP, %	19.86	22.43
Lysine, %	0.97	0.96

^aCON = Control; GLN = Control + 2.5% L-Glutamine.

^bSupplied per kg of diet: Vitamin A (as retinyl acetate), 6,600 IU; Vitamin D (as cholecalciferol), 659 IU; Vitamin E (as α -tocopherol acetate), 66.15 IU; Vitamin K (as menadione sodium bisulfite), 4.35 mg; riboflavin, 11.0; d-pantothenic acid, 22.0 mg; niacin, 33.0 mg; vitamin B₁₂, 22 ug; folate, 1.65 mg; biotin, 0.22 mg.

^cSupplied per kg of diet: Zn (as ZnO), 126.5 mg; Fe (as FeSO₄•H₂O), 126.5 mg; Mn (as MnO), 30.0 mg; Cu (as CuSO₄•5 H₂O), 10.45 mg; I (as Ca(IO₃)•H₂O), 0.29 mg; Se (as Na₂SeO₃), 0.30 mg.

Table 2. Ingredient and calculated nutrient composition of common nursery diet (as-fed basis).

Ingredients, %	
Corn	43.97
Dried whey, 12% CP	20.75
Soybean meal, 46.5% CP	20.00
Fish meal, 60% CP	6.00
Spray-dried animal plasma	4.00
Corn oil	2.50
Dicalcium phosphate	0.69
Salt	0.40
Limestone	0.35
Vitamin premix ^a	0.25
Trace mineral premix ^b	0.15
L-lysine•HCl, 78.8%	0.11
DL-Methionine, 99%	0.10
Calculated nutrient composition	
Lysine, %	1.60
ME, kcal/lb	1,554
Crude fat, %	5.59
NDF, %	6.44
Ca, %	0.90
P, %	0.79
P, avail. %	0.55
Analyzed nutrient composition	
CP, %	23.59
Lysine, %	1.42

^aCON = Control; GLN = Control + 2.5% L-Glutamine.

^bSupplied per kg of diet: Vitamin A (as retinyl acetate), 6,600 IU; Vitamin D (as cholecalciferol), 659 IU; Vitamin E (as α -tocopherol acetate), 66.15 IU; Vitamin K (as menadione sodium bisulfite), 4.35 mg; riboflavin, 11.0; d-pantothenic acid, 22.0 mg; niacin, 33.0 mg; vitamin B₁₂, 22 ug; folate, 1.65 mg; biotin, 0.22 mg.

^cSupplied per kg of diet: Zn (as ZnO), 126.5 mg; Fe (as FeSO₄•H₂O), 126.5 mg; Mn (as MnO), 30.0 mg; Cu (as CuSO₄•5 H₂O), 10.45 mg; I (as Ca(IO₃)•H₂O), 0.29 mg; Se (as Na₂SeO₃), 0.30 mg.

ized to 11 pigs. On day 2 post-farrowing, an injection of iron dextran was administered, needle teeth were clipped, and tails were docked. Boars were castrated on day 7 of parturition. Milk samples were collected on days 7, 14 and 21 after injection of 20 units of oxytocin (Pro Labs Ltd., St. Joseph, MO; 20 USP units/mL) from multiple teats. Blood samples were collected from sows on days 7, 14 and 21 and from weanling pigs (from 4 of 8 pigs per pen) on day 21 post-farrowing.

Weanling Pigs

One hundred twenty-eight pigs (64 barrows and 64 gilts) were weaned on day 21 of lactation and within sow treatment, randomly assigned to one of two nursery treatments: 1) Saline (0.90%) injection on days 1 and 3 postweaning, or 2) 91 μ g/lb body weight *E. coli* Lipopolysaccharide (LPS) injection on days 1 and 3 postweaning. Eight pigs were placed into one of the 16 pens and fed a common starter nursery diet (Table 2). Pigs and feeders were weighed on days 3, 7, 14 and 21 to calculate average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (ADG/ADFI). On days 3 and 7 four pigs per treatment (one pig per pen) were used to measure small intestine characteristics. Small intestine sampling and measurements were performed as previously described in the 2003 Nebraska Swine Report.

Sample Analysis

Plasma and milk samples were deproteinized within 12 hours of collection and immediately frozen and stored at -80°C. Samples remained frozen until glutamine analysis.

Data Analysis

Sow and litter criteria data were analyzed as a completely randomized design with sow and litter as the experimental units, respectively. Nursery growth performance and

(Continued on next page)



intestine characteristics were analyzed as a randomized complete block design with treatments arranged in a 2 × 2 factorial. In the nursery experiment, the model included main effects of sow treatment and nursery treatment and interactions of main effects. Nursery pen was the experimental unit. Data are reported as least squares means.

Results

No differences for sow weight loss, sow feed intake, or litter weight gain (Table 3; $P > 0.15$) were observed between sows fed the CON diets versus sows fed the GLN diet. Sows fed 2.5% supplemental dietary glutamine tended to have increased plasma glutamine concentration on day 7 ($P < 0.11$) and 21 ($P < 0.13$). Additionally, sows fed increased glutamine had 46% and 265% (on days 7 and 21, respectively) greater ($P < 0.08$ and $P < 0.01$, respectively) milk glutamine concentration compared to sows fed the control diet. Weanling pig plasma glutamine concentration (Table 3) did not differ ($P > 0.38$) between pigs that suckled from dams consuming CON versus GLN diets. These data suggest that increased glutamine intake and increased milk glutamine has little effect on sow and litter performance.

Postweaning performance and small intestine characteristics are provided in Table 4. Endotoxin challenge on days 1 and 3 reduced ($P < 0.05$) ADG during days 0 to 3, 3 to 7, and 7 to 14. Daily feed intake was reduced ($P < 0.005$) during days 0 to 3, 3 to 7, 7 to 14, and 14 to 21 by LPS injection. Due to a greater reduction in ADFI relative to ADG, pigs injected with LPS had 40% and 12% greater ADG/ADFI than pigs injected with SAL during days 3 to 7 ($P < 0.0001$) and days 7 to 14 ($P < 0.02$), respectively.

Progeny of sows fed CON diet gained 0.14 lb/d ($P < 0.03$) more

Table 3. Sow and litter growth performance and plasma metabolite concentrations.

Item	CON ^a	GLN ^b	SEM	P-value ^c , <
d - 3 to 7 sow weight loss, lb	39.12	43.17	6.42	NS
d 7 to 14 sow weight loss, lb	7.56	15.94	6.20	NS
d 14 to 21 sow weight loss, lb	0	0.74	3.42	NS
d -3 to 21 sow weight loss, lb	46.66	59.89	9.02	NS
d 0 to 7 weekly sow feed intake, lb	78.45	74.71	5.31	NS
d 7 to 14 weekly sow feed intake, lb	103.37	100.44	6.72	NS
d 14 to 21 weekly sow feed intake, lb	109.57	104.12	4.85	NS
d 0 to 7 litter weight gain, lb	28.38	27.69	1.30	NS
d 7 to 14 litter weight gain, lb	44.67	45.97	1.94	NS
d 14 to 21 litter weight gain, lb	41.16	48.60	1.79	NS
d 0 to 21 litter weight gain, lb	121.19	122.27	4.41	NS
d 7 sow plasma glutamine, mg/dL	6.20	7.27	0.43	0.11
d 21 sow plasma glutamine, mg/dL	4.61	6.31	0.73	0.13
d 7 milk glutamine, mg/dL	1.90	2.77	0.32	0.08
d 21 milk glutamine, mg/dL	2.38	6.31	0.87	0.01
d 21 pig plasma glutamine, mg/dL	5.96	6.35	0.31	NS

^aCON = Control sow diet.

^bGLN = 2.5% sow glutamine diet.

^cNS = $P > 0.15$.

weight during days 3 to 7, and consumed 0.33 lb/d more feed ($P < 0.09$) during days 7 to 14 than progeny of GLN fed sows. During days 0 to 3, progeny of sows fed GLN had the greatest ADG/ADFI when injected with SAL and the lowest ADG/ADFI when injected with LPS (Diet × LPS, $P < 0.05$).

Small intestine length was not influenced ($P > 0.23$) by sow diet or injection type at day 3. Pigs injected with LPS had 34% lower ($P < 0.01$) small intestine empty weight on day 3 compared to pigs injected with SAL. Progeny from sows that consumed CON had 10% greater ($P < 0.10$) small intestine length and 12% greater empty weight on day 7 compared to progeny from sows fed GLN. Pigs injected with LPS had reduced ($P < 0.01$) small intestine weights on day 7 compared to pigs injected with SAL.

Endotoxin challenge reduced ($P < 0.01$) duodenum villus height on day 3 by 22%. Progeny of sows that consumed GLN had 12% greater ($P < 0.05$) villus height on day 3 compared to progeny of sows fed CON. Duodenum villus height on day 7 was similar in progeny from sows fed GLN and injected with LPS compared to progeny from sows injected with SAL (Diet × LPS, $P < 0.05$).

Discussion

Sow weight loss and feed intake were similar during days -5 to 14 compared to other research conducted at University of Nebraska and elsewhere. Litter weight gain of 121 lb during the 21-day lactation was above expected performance.

Our previous research showed improved growth performance and intestinal growth/maturation in weanling pigs when glutamine was present in the diet during an immune challenge. Therefore, improved growth performance (due to enhanced immune response) of immune challenged progeny from sows with greater glutamine intake was expected. However, in the present study, pigs that had previously suckled sows that had increased milk glutamine concentration had generally reduced ADG, ADFI and ADG/ADFI during the 21-day feeding trial. Additionally, progeny from sows fed supplemental glutamine had reduced small intestine length and empty weight on day 7. However, progeny of sows fed supplemental glutamine and injected with endotoxin appeared to maintain duodenum villus height on day 7 compared to progeny of sows fed the control diet.

Apparently, increased dietary glutamine was not metabolized by the sow's intestine because we



Table 4. Day 0 to 21 weanling pig growth performance and small intestine (SI) characteristics.

Criteria, units	CON ^a		GLN ^b		SEM	P < ^e		
	SAL ^c	LPS ^d	SAL	LPS		Diet	LPS	Diet × LPS
ADG, d 0 to 3, lb	0.16	0.051	0.17	-0.27	0.10	NS	0.03	NS
ADFI, d 0 to 3, lb	0.332	0.17	0.32	0.10	0.03	NS	0.0001	NS
ADG/ADFI, d 0 to 3	0.46	0.27	0.52	-4.17	0.85	0.06	0.05	0.05
ADG, d 3 to 7, lb	0.82	0.68	0.73	0.49	0.05	0.03	0.005	NS
ADFI, d 3 to 7, lb	0.93	0.58	0.94	0.42	0.05	NS	0.0001	NS
ADG/ADFI, d 3 to 7	0.89	1.17	0.78	1.18	0.06	NS	0.0001	NS
ADG, d 7 to 14, lb	0.98	0.85	0.96	0.81	0.03	NS	0.02	NS
ADFI, d 7 to 14, lb	1.37	1.06	1.30	0.97	0.04	0.09	0.0001	NS
ADG/ADFI, d 7 to 14	0.71	0.79	0.74	0.83	0.03	NS	0.02	NS
ADG, d 14 to 21, lb	1.08	1.14	1.20	1.16	0.05	NS	NS	NS
ADFI, d 14 to 21, lb	1.74	1.57	1.65	1.48	0.04	0.09	0.005	NS
ADG/ADFI, d 14 to 21	0.63	0.73	0.73	0.79	0.05	NS	NS	NS
SI length, d 3, mm	8.37	8.10	8.94	8.04	0.47	NS	NS	NS
SI empty wt., d 3, lb	0.39	0.27	0.43	0.26	0.04	NS	0.01	NS
SI length, d 7, m	9.11	8.60	7.95	8.21	0.34	0.05	NS	NS
SI empty wt., d 7, lb	0.55	0.43	0.49	0.38	0.03	0.10	0.01	NS
Duodenum VH ^f , d 3, μm	429.67	391.09	515.58	408.57	22.94	0.05	0.01	NS
Jejunum VH, d 3, μm	314.27	325.67	341.65	279.70	28.70	NS	NS	NS
Duodenum VH, d 7, μm	621.64	429.78	545.16	521.43	28.22	NS	0.005	0.05
Jejunum VH, d 7, μm	437.39	347.23	334.02	311.74	40.49	NS	NS	NS

^aCON = Control sow diet.

^bGLN = 2.5% glutamine sow diet.

^cSAL = Saline injection.

^dLPS = Lipopolysaccharide injection.

^eNS = P > 0.10.

^fVH = Villus height; d 0 duodenum VH = 420.77; d 0 jejunum VH = 367.84.

observed a slight numerical increase in plasma glutamine concentration. Moreover, increased milk glutamine concentration was observed on day 7 and day 21 of lactation.

Greater glutamine intake (during suckling) may have altered the absorption or utilization of systemic (enteral and arterial) glutamine. Glutaminase is required for the catabolism of glutamine to glutamate and ammonium and is most likely the first step in use of glutamine as an energy source for cellular proliferation. Therefore, increased plasma glutamine may signal to the intestine to decrease glutamine catabolism and subsequently decrease intestinal growth.

It has been shown that glutamine synthetase (required for synthesis of glutamine from glutamate and ammonium) is important for intestinal differentiation. Therefore, absorption or arterial recruitment of glutamate and ammonia would be important for intestinal growth during an endotoxin challenge provided adequate glutamine synthetase protein is present. It is possible that the expression of glutamine synthetase or glutamate

transporters may decrease with the presence of high concentrations of enteral glutamine and this may correspond with changes in feed intake. The results observed in this experiment may be a result of decreased luminal glutamine absorption and/or glutamine synthesis capacity due to increased glutamine consumption while suckling (i.e., down regulation of amino acid transporter and/or glutamine synthetase expression). However, if this were the underlying mechanism, the maintenance of duodenum morphology cannot be explained. It may be possible that the arterial, in contrast to luminal glutamine (in pigs suckling glutamine supplemented sows) is required prevent a possible endotoxin block on intestinal glutaminase. However, the exchange of arterial versus luminally derived glutamine for intestinal maintenance is unclear and in this experiment we did not observe an increase in plasma glutamine in newly weaned pigs. Additionally, the reduction in growth performance may be explained by a shift of glutamine (and possibly other nutrients)

towards the small intestine enterocytes and away from other tissues. However, without knowledge of first-pass (versus second pass) plasma glutamine and intestinal enzyme expression of glutamine synthetase and glutaminase, this theory can not be substantiated.

Conclusion

The data from this experiment suggest that increased sow consumption of glutamine does not improve the immune response of endotoxin-treated progeny following weaning. However, it appears that duodenum villus height may be maintained in pigs challenged with endotoxin if they previously consumed milk with greater concentrations of free glutamine (due to increased sow glutamine intake).

¹Steve J. Kitt was a graduate student and is currently employed by ADM, Des Moines, IA., Phillip S. Miller is a professor, and Robert L. Fischer is a research technologist and graduate student in the Department of Animal Science.



Energy and Nitrogen Utilization of Corn Rootworm Protected Corn (Event MON 863) and Similar Non-Transgenic Corn in Young Pigs

Robert L. Fischer
Phillip S. Miller¹

Summary and Implications

This experiment was conducted to compare the nutritional value, measured by digestible and metabolizable energy, and nitrogen digestibility in young pigs fed either corn rootworm protected test corn (event MON 863, RX740CRW) or a genetically similar non-transgenic control corn (RX740). The experiment used 12 barrows with an initial body weight of 74.5 lb. The pigs were housed individually in stainless steel metabolism crates and were randomly allotted to one of two corn treatments, either corn rootworm protected corn or non-transgenic control corn. Diets were formulated to contain 97.5% of test or control corn and 2.5% minerals and vitamins. The duration of the experiment was 14 days, which included a seven-day adaptation period followed by a seven-day total fecal and urine collection period. Feed intake was based on initial body weight and pigs had ad libitum access to water. Dry-matter intakes (2.38 versus 2.36 lb/d) and apparent dry matter digestibility (87.78 and 87.71%) were similar ($P > 0.10$) between the corn rootworm protected corn and non-transgenic control corn, respectively. The apparent digestible energy (1.78 versus 1.79 Mcal/lb) and the apparent metabolizable energy (1.73 versus 1.74 Mcal/lb) were similar ($P > 0.10$) between the corn rootworm protected corn and non-transgenic corn, respectively. The nitrogen balance data indi-

cated no differences ($P > 0.10$) between the corn rootworm protected corn and non-transgenic control corn for nitrogen intake (0.04 versus 0.04 lb/d), nitrogen digested (0.03 versus 0.03 lb/d), nitrogen retained (0.01 versus 0.01 lb/d), or nitrogen digestibility (77.30 versus 78.30%), respectively. The results of this experiment indicate that energy and nitrogen utilization are similar between diets containing either the corn rootworm protected corn or non-transgenic control corn when fed to young pigs. Thus, this transgenic corn can be fed to young pigs without negatively affecting nitrogen or energy digestibility.

Introduction

Transgenic crops offer producers a variety of agronomic benefits. Crops with microbial Bt formulations contain the Cry (crystalline protein inclusions) insect control proteins. Following the consumption of the Cry proteins, cells in susceptible insects form selective channels in the cell membrane, which allows an influx of water into the cell. The cells swell due to an influx of water which leads to death of susceptible insects. The test event, MON 863, protects against corn rootworm (CRW, *Diabrotica*). A previous swine finishing study demonstrated that corn containing event MON 863 had similar feeding value to that of non-transgenic control and commercial reference hybrids. In support of the previous study, the current study was conducted to determine the digestible

energy, metabolizable energy and nitrogen digestibility in young pigs to provide an index of the nutritional value of corn rootworm corn (event MON 863) relative to a non-transgenic control.

Procedures

Animals and Treatments

Twelve crossbred [Danbred × (Danbred × NE White Line)] barrows with an average initial body weight of 74.5 lb were used in a completely randomized design. Two diets were formulated to contain 97.5% of one of two varieties of corn (Corn Rootworm Protected Corn; MON 863 or non-transgenic control corn; RX740) and 2.5% minerals and vitamins (Table 1). The amino acid composition of the two corn varieties is shown in Table 2. Diets were formulated such that the test grain was the only source of protein and energy. Diets were fortified with vitamins and minerals to meet or exceed the NRC (1998) requirements for 45-lb pigs. Pigs were housed in stainless steel metabolism crates (4.9 × 1.6 ft) that allowed separate collection of feces and urine. The pigs were housed in an environmentally controlled room and allowed ad libitum access to water through a nipple waterer.

Data and Sample Collection

Pigs were fed in two equal feedings daily (0800 and 1700 h) in a mash form. The metabolism study



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

Item	RX740CRW ^a	RX740 ^a
Ingredient, %		
Corn	97.50	97.50
Dicalcium phosphate	1.25	1.25
Limestone	0.70	0.70
Salt	0.30	0.30
Vitamin premix ^b	0.15	0.15
Trace mineral premix ^c	0.10	0.10
Composition, analyzed		
Dry matter, %	89.38	89.19
Crude protein, %	9.41	9.41
Gross energy, Mcal/lb	1.79	1.79

^aRX740CRW — Corn rootworm protected corn (event MON 863) and RX740 — non-transgenic control corn.

^bSupplied per kilogram of diet: retinyl acetate, 4,400 IU; cholecalciferol, 440 IU; α -tocopherol acetate, 24 IU; menadione sodium bisulfite, 3.5 mg; riboflavin, 8.8 mg; d-pantothenic acid, 17.6 mg; niacin, 26.4 mg; vitamin B₁₂, 26.4 μ g.

^cSupplied per kilogram of diet: Zn (as ZnO), 128 mg; Fe (as FeSO₄ • H₂O), 128 mg; Mn (as MnO), 30 mg; Cu (as CuSO₄ • 5 H₂O), 11 mg; I (as Ca(IO₃) • H₂O), 0.26 mg; Se (as Na₂SeO₃), 0.3 mg.

Table 2. Amino acid analysis of individual ingredients, as-fed basis.

Item	Corn	
	RX740CRW ^a	RX740 ^a
Amino acids, %		
Alanine	0.58	0.60
Arginine	0.43	0.39
Aspartic acid	0.55	0.51
Glutamic acid	1.49	1.51
Glycine	0.30	0.28
Histidine	0.22	0.20
Isoleucine	0.23	0.21
Leucine	0.94	0.96
Lysine	0.23	0.21
Phenylalanine	0.37	0.36
Serine	0.40	0.40
Threonine	0.30	0.27
Tyrosine	0.24	0.23
Valine	0.32	0.29

^aRX740CRW — Corn rootworm protected corn (event MON 863) and RX740 — non-transgenic control corn.

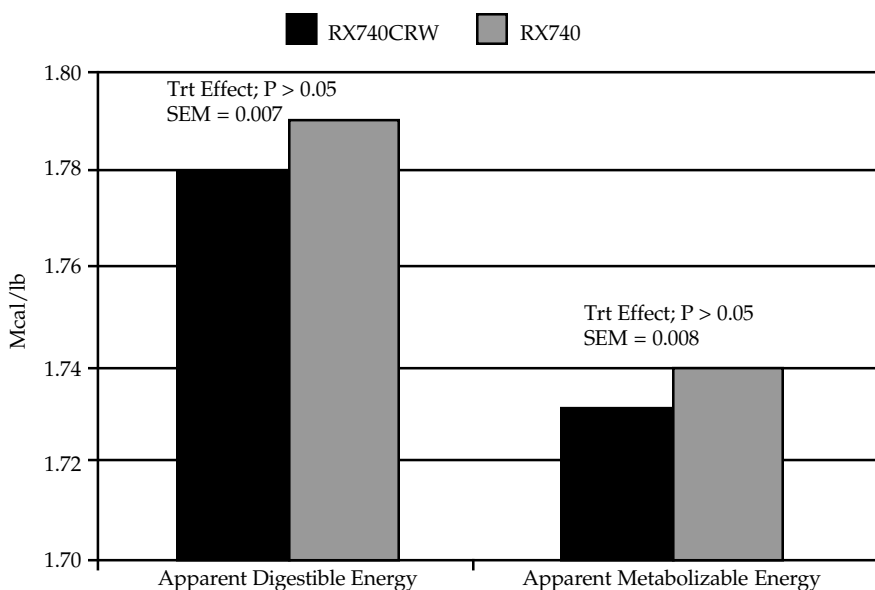


Figure 1. Effect of diet on apparent digestible energy and apparent metabolizable energy; RX740CRW — Corn rootworm protected corn (event MON 863) and RX740 — non-transgenic control corn.

consisted of a seven-day adjustment period to facilities and diets followed by a seven-day period of separate but total collection of feces and urine. During the seven-day adjustment period, a daily feed intake equivalent to 3.75% of initial body weight was achieved and maintained throughout the seven-day collection period. Fecal and urine collections started at 0800 hours on day 7 and end at 0800 hours on day 14 of the experimental period. Total feces were collected, weighed, composited for each pig, and stored at 0°F until subsequent analyses. Urine was collected once daily into a plastic bottle containing 25 mL of 6 N HCl. Each morning, urine collection from the previous day was strained through glass wool to remove particulate matter and a 10% aliquot was retained, recorded, composited for each pig and stored frozen at 0°F.

Statistical Analysis

Data were analyzed as a completely randomized design using PROC MIXED of SAS (1999). The main effect in the statistical model was genetic corn line (MON 863 and RX740). In all analyses crate was the experimental unit.

Results and Discussion

Dry matter percentage, crude protein percentage and gross energy density of the two corn varieties were similar (Table 1). Dry matter intake (2.38 versus 2.36 lb/d) and apparent dry matter digestibility (87.78 and 87.71%) were similar ($P > 0.10$) between the corn rootworm protected corn and non-transgenic control corn (Table 3). The apparent digestible energy (1.78 versus 1.79 Mcal/lb) and the apparent metabolizable energy (1.73 versus 1.74 Mcal/lb) were similar ($P > 0.10$) between the corn rootworm protected corn and non-transgenic control corn, respectively. The values calculated in this experiment for apparent dry mat-

(Continued on next page)



ter digestibility, apparent digestible energy and apparent metabolizable energy are similar to the published values of Adeola and Bajjalieh (1997) and NRC (1998).

Total nitrogen intake was similar ($P > 0.10$) between the corn varieties (Table 3). The amount of nitrogen digested (0.03 and 0.03 lb/d) and retained (0.01 and 0.01 lb/d) were similar ($P > 0.10$) between the corn rootworm protected and non-transgenic corns, respectively. Likewise, nitrogen digestibility (77.30 and 78.30%; $P > 0.10$) was similar between corns. The values for nitrogen digestibility of the corn varieties used in this experiment are similar to the values published by Lawrence et al. (1995) and Adeola and Bajjalieh (1997).

In conclusion, results of energy and nitrogen balance with growing pigs demonstrate that the potential

Table 3. Energy and nitrogen balance.

Item	RX740CRW ^a	RX740 ^a	SEM	P-Value
No. pigs	6	6		
Initial weight, lb	74.13	74.97	0.430	0.20
Final weight, lb	80.15	80.26	0.571	0.89
Dry matter intake/d, lb	2.38	2.36	0.057	0.83
Apparent dry matter digestibility, %	87.78	87.71	0.321	0.88
Gross energy, Mcal/lb ^{bc}	2.05	2.06	—	—
Apparent digestible energy, Mcal/lb ^{bc}	1.78	1.79	0.007	0.38
Apparent metabolizable energy, Mcal/lb ^{bc}	1.73	1.74	0.008	0.43
Nitrogen intake, lb/d ^c	0.04	0.04	0.001	0.86
Nitrogen digested, lb/d ^c	0.03	0.03	0.001	0.86
Nitrogen retained, lb/d ^c	0.01	0.01	0.001	0.45
Nitrogen digestibility, %	77.30	78.30	0.733	0.36
Nitrogen retention, % of intake	28.02	31.12	2.530	0.41
Nitrogen retention, % of absorbed	36.22	39.67	3.084	0.45

^aRX740CRW — Corn rootworm protected corn (event MON 863) and RX740 — non-transgenic control corn.

^bCalculated on a 100% corn basis.

^cCalculated on a 100% dry-matter basis.

feeding value of corn rootworm protected corn (RX740CRW; event MON 863) is equivalent to that of a genetically similar non-transgenic control variety (RX740). Therefore, corn rootworm protected corn can be used in swine diets without

negatively affecting energy and/or nitrogen digestibility.

¹Robert L. Fischer is a research technologist and graduate student and Phillip S. Miller is a professor in the Department of Animal Science.

Effect of Increasing Dietary Crude Protein Concentration on Growth Performance and Serum Insulin-Like Growth Factor-I Concentration

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Summary and Implications

This study was conducted to investigate the effects of increasing dietary protein intake on growth performance and serum insulin-like growth factor-I (IGF-I) concentration in growing-finishing gilts. Thirty-nine crossbred gilts with an initial body weight of 74.3 lb were used in a 28-day growth study. The gilts were randomly allocated to one of five dietary treatments. The diets were standard corn

soybean meal diets, which were formulated to contain 10, 14, 18, 22, or 26% crude protein by changing the ratio of corn to soybean meal in the diet. Pig and feeder weights were recorded weekly for the determination of average daily gain (ADG), average daily feed intake (ADFI) and feed efficiency (ADG/ADFI). Weekly blood samples were collected to evaluate dietary effects on plasma urea and IGF-I concentrations. There was no difference ($P > 0.10$) in ADFI among the treatments throughout the 28-day experimental period. Dietary protein concentration had significant linear and quadratic effects on ADG and ADG/ADFI ($P < 0.01$). Gilts

fed the diet containing 22% CP had the greatest accretion rate of fat-free lean (0.82 lb/d); however, gilts fed the 18 and 26% CP diets had numerically similar fat-free lean accretion rates. Increased dietary protein concentration resulted in increased cold carcass weight (linear, $P < 0.01$; quadratic, $P < 0.01$) with no differences in carcass dressing percentage. Protein concentration had a significant quadratic effect ($P < 0.01$) on plasma urea and serum IGF-I concentration during weeks 1 thru 4 of the experiment. In summary, dietary protein concentration had significant linear and quadratic effects on final body weight, ADG, feed



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

Item	Dietary protein concentration, %				
	10	14	18	22	26
Ingredient, %					
Corn	89.10	79.00	69.10	59.00	49.00
Soybean meal, 46.5% CP	5.50	15.75	25.75	36.00	46.10
Tallow	3.00	3.00	3.00	3.00	3.00
Dicalcium phosphate	1.05	1.00	0.95	0.85	0.80
Limestone	0.70	0.65	0.58	0.55	0.50
Salt	0.30	0.30	0.30	0.30	0.30
Vitamin premix ^a	0.20	0.20	0.20	0.20	0.20
Mineral premix ^b	0.15	0.15	0.15	0.15	0.15
Analyzed nutrient composition					
Dry matter, %	90.33	90.77	91.04	90.93	91.52
Crude protein, %	9.15	13.60	17.54	22.17	25.82
Lysine, %	0.37	0.64	0.87	1.17	1.37
Calcium, %	0.66	0.71	0.68	0.68	0.77
Total phosphorus, %	0.47	0.54	0.57	0.60	0.69
Crude fat, %	5.08	4.96	4.82	4.57	4.41

^aSupplied per kilogram of diet: retinyl acetate, 4,400 IU; cholecalciferol, 440 IU; α -tocopherol acetate, 24 IU; menadione sodium bisulfite, 3.5 mg; riboflavin, 8.8 mg; d-pantothenic acid, 17.6 mg; niacin, 26.4 mg; vitamin B₁₂, 26.4 μ g.

^bSupplied per kilogram of diet: Zn (as ZnO), 128 mg; Fe (as FeSO₄•H₂O), 128 mg; Mn (as MnO), 30 mg; Cu (as CuSO₄•5 H₂O), 11 mg; I (as Ca(IO₃)•H₂O), 0.26 mg; Se (as Na₂SeO₃), 0.3 mg.

efficiency, fat-free lean gain, cold carcass weight, plasma urea and serum IGF-I concentration. Thus, the interesting finding in this experiment was that the decrease in fat-free lean gain in gilts fed the 14% CP diet was not associated with a decrease in serum IGF-I concentration. This finding suggests that something is inhibiting the actions of IGF-I protein by causing a decrease in protein accretion rate in these gilts. Thus, the future focus of this research is to determine the effects of dietary crude protein and crystalline amino acids on serum IGF-I concentration.

Introduction

Excessive excretion of nitrogen by livestock operations is a major environmental concern. A consequence of excess nitrogen excretion is the potential for leaching of nitrates into groundwater and from runoff of nitrates into surface water. Thus, a major factor that has stimulated interest in the use of low-protein amino-acid supplemented diets is this potential impact on the environment. It is estimated that when growing-finishing pigs are fed low-protein amino acid-supplemented diets

there is a 30% reduction in nitrogen excretion. Nutritional and hormonal factors are major determinants of animal growth, but the mechanisms of how protein (amino acids) influence the hormonal control of protein accretion in growing animals remains relatively undefined. Protein accretion in growing animals is mediated indirectly by pituitary growth hormone. When growth hormone is bound to specific receptors, it stimulates the production of insulin-like growth factor-I (IGF-I). Although growth hormone is the primary stimulus for IGF-I synthesis, many nutritional factors (i.e., protein intake, energy intake, and essential amino acid intake) affect the production and action of IGF-I in the growing animal. Therefore, the current research seeks to fill the gaps in our current knowledge of how the use of crystalline amino acids affects protein accretion by gaining a greater understanding of how IGF-I is affected by the dietary concentration of crude protein (amino acids) in swine growing-finishing diets.

The long-range goal of this research is to determine the concentrations of essential amino acids and the dietary protein ingre-

dient (protein-bound versus crystalline amino acids) that will optimize IGF-I expression in growing-finishing pigs to maximize protein accretion. The objective of this experiment (first step toward attaining our long-range goal) is to demonstrate *in vivo* the effect of increasing dietary protein intake on serum IGF-I concentration.

Procedures

Animals and Treatments

Thirty-nine crossbred [Danbred \times (Danbred \times NE White Line)] gilts were used in a 28-day growth study. Pigs averaged 74.3 and 126.3 lb at the initiation and termination of the experiment, respectively. Four gilts were randomly selected for an initial slaughter group for the collection of tissue samples. The remaining 35 gilts were randomly assigned to one of five dietary treatments. The diets (Table 1) were standard corn soybean meal diets, which were formulated to contain 10, 14, 18, 22, or 26% crude protein (CP) by changing the ratio of corn to soybean meal in the diet. Diets were fortified with vitamins and minerals to meet or exceed the NRC (1998) requirements for 45-lb pigs. The pigs were housed in an environmentally controlled room and allowed ad libitum access to feed and water throughout the experiment.

Data and Sample Collections

Pig and feeder weights were recorded weekly for the determination of average daily gain (ADG), average daily feed intake (ADFI) and feed efficiency (ADG/ADFI). Fat-free lean gain (FFLG) was calculated from backfat (BF) thickness and longissimus muscle area (LMA); BF and LMA were obtained on the first and the last day of the experiment using real-time ultrasound using the National Pork Producers Council (1991) equation. Plasma urea and serum insulin-like growth

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Table 2. Effect of protein concentration on growth performance of growing gilts.

Item	Dietary protein concentration, %					SEM	Linear	Quadratic
	10	14	18	22	26			
Number of pigs	7	7	7	7	7			
Growth performance								
Initial wt., lb	73.65	74.75	74.31	73.43	74.75	0.827	NS	NS
Final wt., lb	106.07	127.67	131.42	133.62	132.30	2.624	< 0.01	< 0.01
d 0 to 28								
ADG, lb ^a	1.15	1.87	2.03	2.14	2.05	0.073	< 0.01	< 0.01
ADFI, lb ^b	4.06	4.41	4.01	4.17	3.95	0.141	NS	NS
ADG/ADFI	0.28	0.42	0.51	0.52	0.52	0.010	< 0.01	< 0.01
Lysine intake, g/d	6.82	12.77	15.81	22.12	24.51	0.647	< 0.01	NS
Ultrasound measurements								
Initial								
Backfat, in	0.32	0.34	0.34	0.32	0.33	0.015	NS	NS
LMA, in ^{2c}	2.44	2.39	2.36	2.43	2.45	0.064	NS	NS
Final								
Backfat, in	0.47	0.51	0.44	0.38	0.41	0.017	< 0.01	NS
LMA, in ²	3.01	3.82	4.01	3.92	4.04	0.123	< 0.01	< 0.01
FFLG, lb/d ^{d e}	0.35	0.69	0.80	0.82	0.80	0.035	< 0.01	< 0.01
Carcass measurements								
Cold carcass wt., lb	78.79	96.00	98.64	99.36	99.14	1.962	< 0.01	< 0.01
Dressing, %	74.38	75.23	75.00	74.32	74.87	0.504	NS	NS

^aADG = average daily gain.

^bADFI = average daily feed intake.

^cLMA = longissimus muscle area.

^dFFLG = fat-free lean gain.

^eCalculated from equation of NPPC, 1991.

factor-I (IGF-I) concentrations were determined in blood collected weekly throughout the experiment.

Statistical Analysis

Data were analyzed as a completely randomized design using PROC MIXED of SAS (1999). The main effect in the statistical model was dietary protein concentration (10, 14, 18, 22, and 26% CP). In all analyses, pig was the experimental unit. Only linear and quadratic effects are presented for variables in which the main effect of CP was significant.

Results and Discussion

Growth Performance

The response of ADG, ADFI and ADG/ADFI to dietary treatments are shown in Table 2. There was no difference ($P > 0.10$) in ADFI among the treatments throughout the 28-day experimental period.

Protein concentration had significant linear and quadratic effects on ADG and feed efficiency ($P < 0.01$). Average daily gain increased as the dietary concentration of crude protein increased from 10% (1.15 lb/d) to 22% dietary CP (2.14 lb/d; a 54% improvement in gain) then slightly decreased in gilts fed the diet containing 26% CP (2.05 lb/d). Feed efficiency followed a similar pattern as ADG. Gilts fed the 10% dietary CP had the lowest ADG/ADFI (0.35) and those fed the diets containing 22% and 26% CP had the greatest ADG/ADFI (0.52; a 62% improvement in feed efficiency).

Carcass Characteristics

Real-time ultrasound measurements recorded on days 0 and 27 are summarized in Table 2. At the initiation of the experiment there were no differences ($P > 0.10$) in tenth-rib BF depth or LMA among the dietary treatments. However, at the end of the experiment, there

was a significant linear effect of dietary protein ($P < 0.01$) on tenth-rib BF depth and linear and quadratic effects ($P < 0.01$) on LMA. Gilts fed the diet containing 22% CP had the lowest BF (0.38 in) and gilts fed the 14% CP diet had the greatest BF (0.51 in). The greater amount of BF detected in the gilts fed the diet containing 14% CP could be due to the numerically greater ADFI observed for these gilts. Longissimus muscle area was similar among the gilts fed the diets containing 14% through 26% CP (3.82, 4.01, 3.92, 4.04 in², respectively); however, gilts fed the 10% dietary CP had a reduction in LMA (3.01 in²). Protein concentration had a significant quadratic effect on fat-free lean ($P < 0.01$). Gilts fed the diet containing the 22% CP had the greatest accretion rate of fat-free lean (0.82 lb/d). Gilts fed the 18 and 26% CP diets had numerically similar fat-free accretion rates (0.80 and 0.80 lb/d, respectively). The

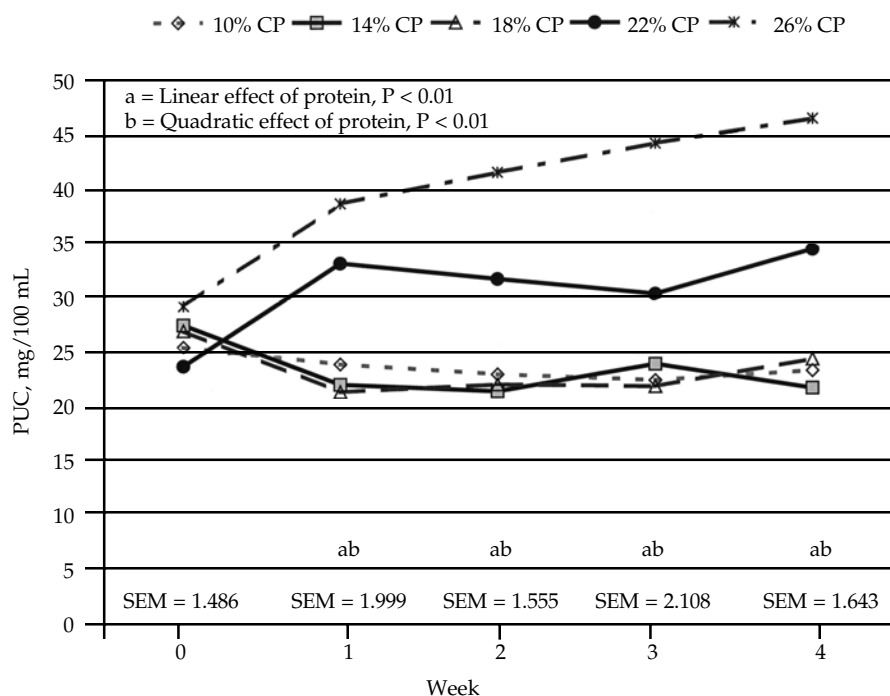


Figure 1. Response of plasma urea concentration (PUC) to experimental diets by week.

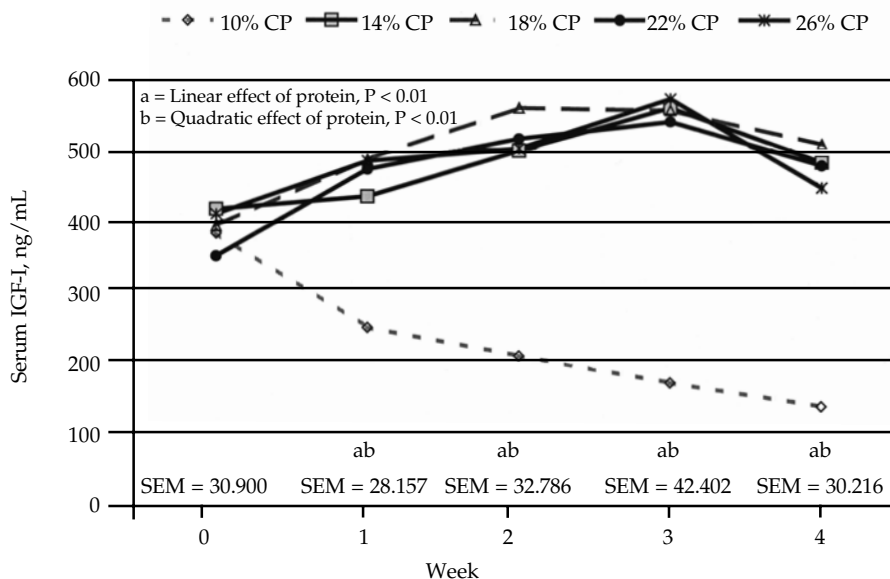


Figure 2. Response of serum insulin-like growth factor-I (IGF-I) to experimental diets by week.

NRC (1998) requirements for swine suggest a total lysine intake of 17.5 grams/day for pigs weighing 44 to 110 lb and accreting 0.72 lb/day of fat-free lean. Thus, gilts fed the diets containing 10 and 14% CP consumed approximately 7 and 13 grams of lysine/day, respectively, which was less than the amount

suggest by the NRC (1998) to maximize fat-free lean accretion. Thus, the fat-free lean data suggest that the CP requirement for gilts in the present study was $\geq 18\%$ from 74 to 126 lb of body weight. Increased dietary protein concentration resulted in increased cold carcass weight (quadratic, $P < 0.01$) with

no differences in carcass dressing percentage.

Blood Metabolites

The effects of dietary crude protein on plasma urea concentration are illustrated in Figure 1. Protein concentration had significant linear and quadratic effects ($P < 0.01$) on plasma urea concentration during weeks 1 thru 4 of the experiment. Gilts fed the 10, 14 and 18% CP diets had similar plasma urea concentrations throughout the experiment. While gilts fed the 22% CP diet had an intermediate concentration of plasma urea, and gilts fed the 26% CP diet had the highest plasma urea concentration. The plasma urea data indicate that the CP requirement for gilts during the four-week experimental period was $\geq 18\%$ CP which also was supported by the FFLG data.

Serum IGF-I concentrations are presented in Figure 2. Protein concentration had significant linear and quadratic effects ($P < 0.01$) on serum IGF-I concentration during weeks 1 thru 4 of the experiment. Gilts fed the diet containing 10% CP had the lowest IGF-I concentration throughout the experiment and gilts fed the 18% CP had the highest IGF-I concentration during the experiment, except during week 3. These serum IGF-I concentrations indicate that the production and release of IGF-I into the blood is inhibited by the consumption of a 10% CP diet. This reduction in serum IGF-I is supported by the low fat-free lean accretion rates calculated in the gilts consuming the 10% crude protein diet. However, gilts fed the 14, 18, 22 and 26% CP diets had numerically similar serum IGF-I concentrations. However, gilts fed the 14% CP diet had a significant decrease in FFLG as compared to gilts fed the 18, 22, and 26% CP diets. These results would suggest that the consumption of a diet slightly deficient in CP (14%) does not inhibit the pro-

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duction of IGF-I. However, the actions of IGF-I in the body (i.e., muscle protein accretion) are in some way inhibited (i.e., receptor binding, receptor concentration, IGF-I binding proteins) which is supported by the reduction in FFLG in gilts fed the 14% CP diet.

Conclusions

The results from this experiment demonstrate that growing gilts respond to increased dietary crude protein concentration, which is supported by the improvement in ADG, feed efficiency and fat-free lean gain in gilts fed up to 22% crude protein.

A similar effect was detected in plasma urea concentration. Gilts fed the 22% CP diet had an increase concentration of plasma urea compared to the gilts fed the 10, 14 and 18% CP diet, indicating that the CP requirement of gilts in this experiment was $\geq 18\%$ CP. However, serum IGF-I concentrations were only decreased in gilts fed the 10% CP diet, indicating that the consumption of a diet below the gilts dietary crude protein requirement (14%) was not always associated with a reduction in IGF-I serum concentration. Thus, future research in this area will focus on the relationship between carcass protein

accretion and serum IGF-I concentration. Also, the effect of crystalline amino acids will be investigated to determine their effects on serum IGF-I concentration and how the pattern of dietary crystalline amino acid supplementation can be manipulated in diets for growing-finishing pigs without having a negative effect on carcass protein accretion rates.

¹Robert L. Fischer is a research technologist and graduate student and Phillip S. Miller is a professor in the Department of Animal Science.

Different Biological Responses of Pigs of Two Genetic Populations to PRRSV Challenge Suggests Underlying Genetic Variation in Susceptibility/Resistance to PRRSV

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Summary and Implications

The objective was to determine whether genetic variation in susceptibility to Porcine Respiratory and Reproductive Syndrome virus (PRRSV) exists. One hundred pigs from each of two distinctly different populations (NE Index Line, I, and Duroc-Hampshire cross pigs, DH) were challenged with PRRSV at 26 days old. A littermate to each challenged pig was included in the experiment without PRRSV challenge to serve as a control. Body weight and temperature were recorded and

blood samples were drawn from all pigs on the day of challenge and 4, 7 and 14 days post-challenge. All pigs were sacrificed and a necropsy was performed on day 14. At necropsy, lungs were scored for evidence of interstitial pneumonia, lung tissue was collected for microscopic evaluation to determine incidence and severity of lesions, and aliquots of lung, lymph and spleen tissue were collected and stored. Interactions of line by challenge (PRRSV negative vs. PRRSV positive) were significant for several traits. I pigs challenged with PRRSV had greater weight gain, lower temperatures, replicated virus at lower rates in lungs, and lymph nodes, had fewer lesions, and lower ELISA values than DH pigs. Changes in temperature with time were similar for unchallenged I and DH pigs, and unchallenged DH pigs grew significantly faster than

I pigs. Response of pigs of the two lines to PRRSV challenge differed indicating underlying genetic variation exists. Future research with tissues collected will determine which genes are expressed differently in pigs with resistant and susceptible responses to PRRSV.

Introduction and Background

Disease costs the swine industry more than \$1.5 billion a year and Porcine Reproductive and Respiratory Syndrome Virus (PRRSV) is currently the most economically significant infectious disease. PRRSV is an enzootic virus that targets pulmonary alveolar macrophage and causes pneumonia. It may cause abortion, premature farrowing, stillborn and mummified pigs and respiratory disease.



Increased death loss and chronic poor performance in nursing and weaned pigs occur in some herds.

Pigs can be infected with PRRSV in a variety of ways including placental transmission from naive dams that are exposed to the virus during gestation, in mammary secretions of dams exposed in late gestation, pig-to-pig contact and in semen. In addition, contaminated clothing, needles, and flies and mosquitoes have been identified as vectors in transmission of PRRSV.

Approaches used to manage PRRS are costly and relatively ineffective as long-term solutions. However, natural resistance to some diseases in animals has been found to be heritable and there is substantial evidence for genetic control of susceptibility to certain diseases. Genomics research has identified genes that affect disease traits. Therefore, a possible alternative practice to reduce the incidence and severity of PRRSV infections is selection for genetic resistance.

The difficulty is that selection for disease resistance using traditional methods is very difficult. Selection will be more effective if genes that confer resistance are identified. Currently, knowledge of the genetic basis of resistance or susceptibility to infectious diseases is limited. Because of the difficulties in improving disease resistance in farm animals by traditional selection, achievement of such improvement is one of the most important applications of genomic research. The major hurdle is the collection of informative disease records to enable the segregation of disease resistance genes to be traced in pedigrees. Once linkage has been established, the location of the genes may be further refined and lead to molecular characterization of the causative gene(s).

It is especially important to identify traits that differentiate animals that respond differently to disease challenges and to begin to build the phenotypic and genotypic records

to identify the genes involved. A project was initiated at Nebraska with just such an objective. Pigs from two distinct populations were challenged with PRRSV and their response for several traits was characterized. Blood, lung, lymph, and spleen tissue were collected for future research to determine which genes are involved in the different patterns of resistance/susceptibility that were observed. The purpose of this report is to describe this project and to characterize the phenotypic responses of pigs of the two populations and to briefly describe future research that will be done to identify the genes involved.

Materials and Methods

A total of 200 pigs from each of the NE Index line (I), a Large White-Landrace composite population that has been selected for increased litter size for 20 generations, and a cross of Duroc and Hampshire lines (DH) that have been selected exclusively for rate and efficiency of lean growth were used. One-half of them were challenged with PRRSV; the other half, which were littermates to the challenged pigs, were not challenged and served as controls. The experiment was conducted in two replicates within each of two years with 50 pigs per breed in each year/replication.

The pigs were selected at random from the available litters. Two pigs of the same sex from as many different litters and families as possible, representing a total of 83 sires and 163 dams, were sampled to broadly represent the populations. One pig per litter was designated to be the control and the other to receive the inoculation of PRRSV.

Pigs were transported to the University of Nebraska Veterinary and Biomedical Sciences (VBS) Animal Research Facility and placed in environmentally controlled rooms with 25 pigs per room. Each room contained one pen of pigs of each line with 12 to 13 pigs per pen.

After a three-day acclimation period, pigs in rooms designated for PRRSV challenge were inoculated with 1 cc of virus per nostril. The virus used was the PRRSV RFLP-Iowa Strain, the standard virulent strain used by the VBS virology lab of F. Osorio.

Average age and weight of pigs when inoculated were 26 days and 11.5 lb., respectively. Pigs were given ad libitum access to water and feed. A diet formulated to contain 21% crude protein, 1.20% lysine, 0.80% calcium, 0.70% phosphorus and 1550 kcal/lb ME was fed. Temperature was maintained between 78 and 84°F.

Body temperature by rectal probe and weight of all pigs were recorded on the day of inoculation (d0) and 4, 7, and 14 days after inoculation and blood was drawn on each day. On day 14, all pigs were sacrificed and necropsy was performed. Lungs were scored for incidence and severity of lesions, and samples of lung, lymph and spleen were collected.

Level of viremia, a measure of the pig's ability to replicate PRRSV, was measured with viral titration and the number of infected cells in blood samples drawn on each day, and in lung, lymph and spleen tissue. An ELISA® (Pseudorabies Virus Antibody Test Kit (Herd Check) Idexx Laboratories, Inc.) test was conducted in each blood sample to determine antibody to PRRSV. Representative sections of lung from each animal were fixed on slides and scored from 0 to 3 for severity of lesions.

Data were analyzed to determine whether I and DH pigs differed in response to PRRSV, which is evidence that genetic variation exists. Appropriate models to account for sampling of sires and dams from the different populations and for repeated measures on pigs were used. Age was fitted as a covariate to adjust records for all pigs to the same starting age.

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Results

Pigs infected with PRRSV gained less weight ($P < 0.001$) during each interval than their uninfected littermates (Figure 1), but the pattern of response during the three intervals was different between lines (interaction of line \times challenge and line \times challenge \times interval, $P < 0.001$). Unchallenged DH pigs gained more rapidly than I pigs, especially during the last seven days of the trial. PRRSV challenged I pigs, however, gained more from day 4 to day 7 and from day 7 to day 14 than infected DH pigs.

Changes in rectal temperature from day 0 to day 14 also were different for challenged and unchallenged pigs of the two lines. DH pigs had greater temperature than I pigs ($P < 0.001$) and mean temperature increased in both lines from day 0 to day 14 ($P < 0.001$). The pattern of response for unchallenged pigs was similar in both lines, whereas the response in challenged littermates was quite different. Temperature increased most rapidly in DH pigs, especially from day 0 to day 4, and remained higher to day 14. This pattern of higher temperature in DH pigs than I pigs is consistent with the pattern of growth rate in the two lines and indicates PRRSV had a greater effect in DH than I pigs. Taken together, the different patterns of weight gain and temperature in response to PRRSV indicates underlying genetic variation with possibly greater resistance in line I.

Infection with PRRSV was confirmed with the ELISA test. Pigs with an ELISA level of 0.4 or greater are classified as PRRSV positive; however, the test can be in error and result in both false positive and false negative classifications. ELISA levels of challenged pigs ranged from 0.18 to 3.38, 88% had levels ≥ 0.40 . ELISA levels of unchallenged littermates ranged from 0 to 1.11, 99% had values ≤ 0.40 . Mean ELISA levels of challenged pigs at day 14 were higher

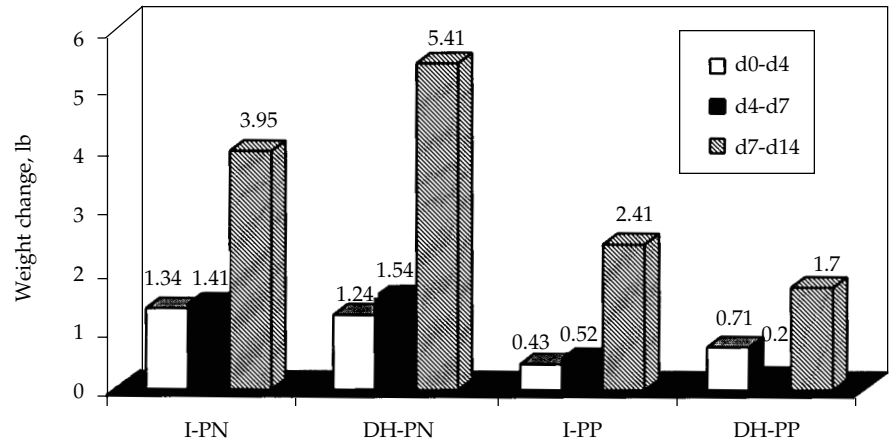


Figure 1. Weight change from day 0 to 4, d 4 to 7, and d 7 to 14 for Index (I) and Duroc-Hampshire cross (DH) pigs without (PN) and with (PP) PRRSV challenge: Challenge, Line \times challenge, and Line \times challenge \times interval: $P < 0.001$.

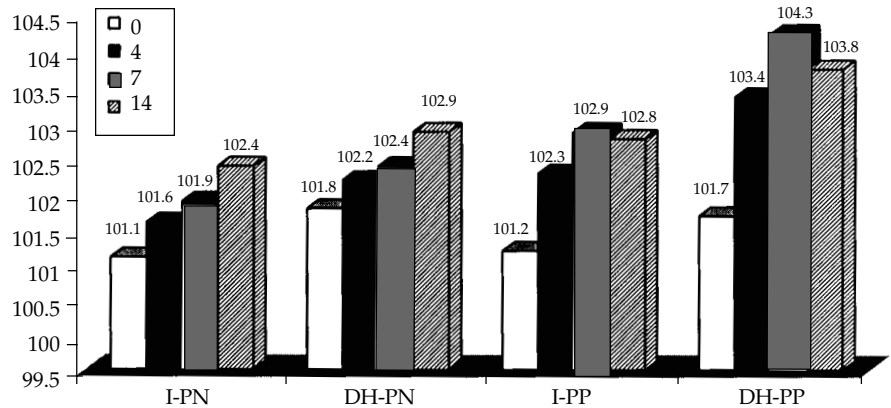


Figure 2. Rectal temperature (F) at day 0, 4, 7, and 14 for Index (I) and Duroc-Hampshire cross (DH) pigs without (PN) and with (PP) PRRSV challenge (Line, challenge, line \times challenge, line \times challenge \times day; $P < 0.001$).

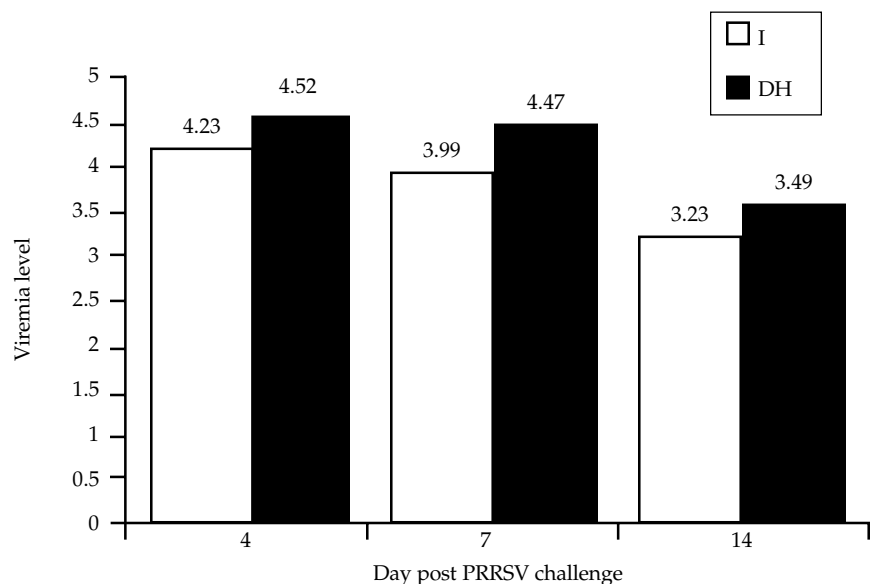


Figure 3. Viremia level (number of plaque forming colonies per deciliter of blood) measured as \log_{10} in serum of Index (I) and Duroc-Hampshire cross (DH) pigs at 4, 7, and 14 days post PRRSV challenge (Line effect, $P < 0.001$).

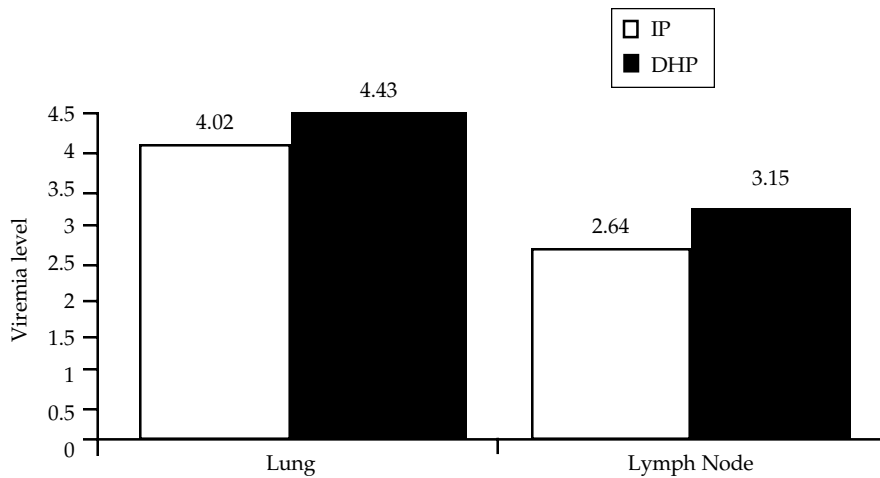


Figure 4. Viremia level, \log_{10} at d 14 in the lung (line effect, $P = 0.11$) and lymph nodes (line effect, $P = 0.07$) of Index (I) and Duroc-Hampshire cross (DH) pigs challenged with PRRSV.

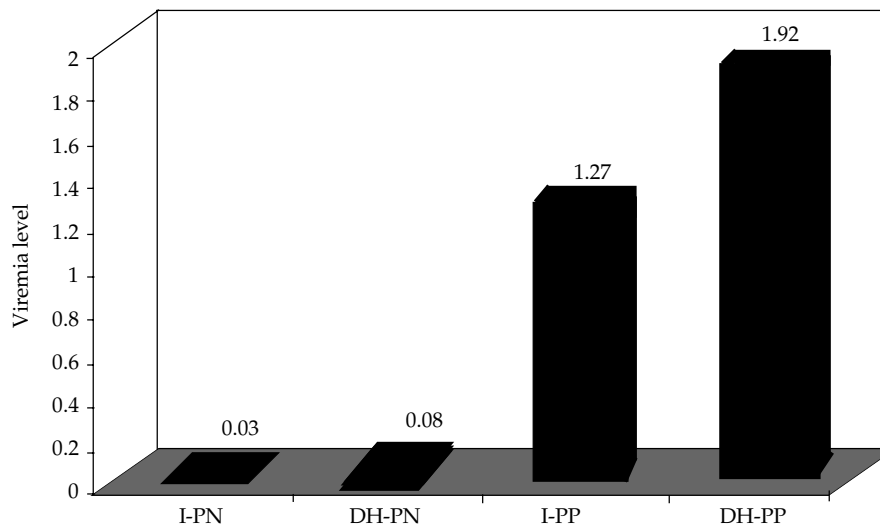


Figure 5. Lung lesion score (scale of 0 to 3) for Index (I) and Duroc-Hampshire (DH) cross pigs without (PN) and with (PP) PRRSV challenge (Line and line x challenge, $P < 0.001$).

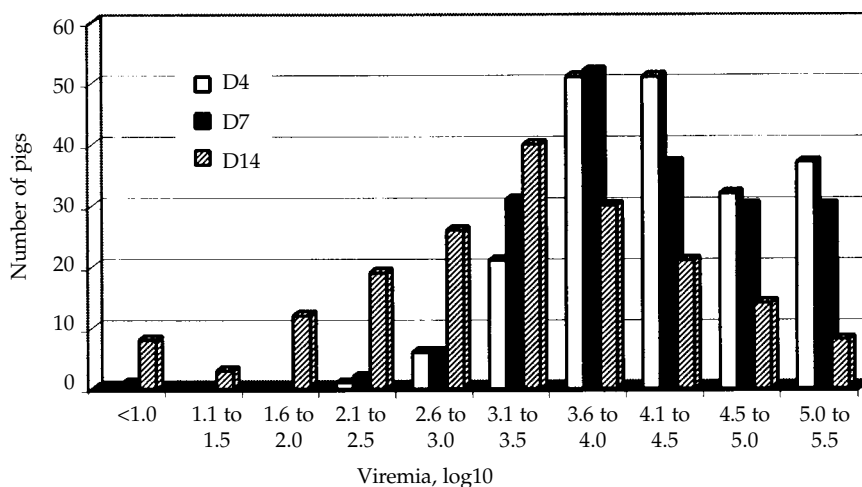


Figure 6. Distribution of blood serum viremia, \log_{10} across all pigs.

in DH pigs than in I pigs (1.33 vs. 1.10, $P = 0.0009$).

Mean viremia level, which measures the pig's ability to replicate PRRS virus, is illustrated in Figure 3. Viremia could be recorded only in blood drawn from challenged pigs at day 4, day 7, and day 14. Viremia level is measured on an exponential scale and the values in the graph are base 10 logarithms, so differences in exponents represent exponentially greater differences in number of viral plaques. For example, the coefficients of 4.23 and 4.53 for I and DH pigs at day 4 represent a two-fold increase in number of units ($10^{4.23} = 16,982$ and $10^{4.52} = 33,113$). Blood viremia level was greater in DH than I pigs on each day, but unlike weight gain and body temperature, line x day interaction was not significant ($P > 0.30$). Viremia recorded in lung tissue and lymph nodes is illustrated in Figure 4. As for blood serum, DH pigs had greater levels than I pigs (lung, $P = 0.11$; lymph, $P = 0.07$).

Lungs were first scored for incidence of pneumonia (yes or no) and then incidence of lesions in lungs of pigs with pneumonia was scored as 1 (few lesions), 2 (moderate), or 3 (severe). Mean score is illustrated in Figure 5. Lesions were observed in a few unchallenged pigs, but the incidence was very low for both I and DH pigs. Mean score was greater ($P < 0.001$) for DH than I pigs challenged with PRRSV.

Discussion and Implications

There was considerable variation among pigs within both genetic lines in response to PRRSV. The distribution of viremia across all pigs is illustrated in Figure 6. Some pigs replicated the virus at very high rates, as high as $10^{5.5}$, or 316,228 plaque units per deciliter of blood. Other pigs had replication rates as low as 10^{-7} , or 5 plaque units per deciliter of blood. High levels of viremia tended to be

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associated with low weight gain, higher rectal temperature and increased incidence of lung lesions, but correlations among these variables were low (ranging from -.59 to .03). Some pigs replicated the virus at high rates and showed all the clinical symptoms of PRRS. They grew slowly, had high body temperature, and had lung lesions indicating interstitial pneumonia. Other pigs with similar levels of viremia showed few symptoms of PRRS. They gained weight at normal rates, had normal or only slightly elevated body temperature, and had few lung lesions. Similarly, there were pigs in this sample with relatively low levels of viremia that showed typical symptoms of PRRS,

whereas others showed few clinical effects of the virus.

Line differences and line by challenge interactions across days are evidence of genetic mechanisms involved in immune responses to PRRSV. The nature of these genetic differences or whether it is possible to select for greater resistance cannot be determined from the data collected so far. The next step in this research will be to investigate differences in expression of specific genes in the resistant/susceptible classes of pigs. The focus will be on genes expressed in macrophage cells in the lung, but genes expressed in other tissues involved in immune responses (e.g., lymph and spleen) could also be impor-

tant. Because of the difficulty in applying quantitative methods to select for PRSSV resistance, experiments to identify the genes involved are critical as it is unlikely that genetic change can occur until selection directly for these genes in the absence of PRRSV can be applied.

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Major Genes Affect Reproduction and Early Growth

J. W. Holl
R. K. Johnson¹

Summary and Implications

The Nebraska Index Line is reproductively superior to its contemporary control, producing approximately four pigs more per litter. However, the genes or quantitative trait loci (QTL) that cause these differences are unknown. A previous study with an F₂ resource population created by crossing the NE Index and Control lines identified one QTL affecting ovulation rate, one QTL affecting number of fully formed fetuses, one QTL affecting number of pigs born alive, two QTL affecting number of stillborn pigs, five QTL affecting nipple number, and six QTL affecting age at puberty. However, individual birth weight and weaning weight had not been included in the analyses. In addition, improved statistical models with greater power to identify QTL and test for additional kinds of gene action have been developed. The objective of this experiment was to

apply these more powerful models to the data from the F₂ resource population to identify additional chromosomal regions that contain genes that affect reproduction and early growth. Using standard statistical techniques identical to those used in the previous analyses, evidence was found for QTL (P < 0.10) affecting birth weight on chromosomes (C) 8 and 12. Additive effects of the C8 and C12 alleles inherited from the control line were -20 ± 17 g and -59 ± 19 g, and dominance effects were 85 ± 31 g and -73 ± 37 g, respectively. No QTL were detected for weaning weight. While fitting the largest QTL for the respective trait as a background effect to increase the statistical power, additional QTL affecting number of stillborn pigs on C12, fully formed pigs on C6, and ovulation rate on C15 and C8 were identified. No additional QTL were detected for number born alive, nipple number, age at puberty, or birth weight. Statistical procedures to test for imprinting or parent-of-origin effects were then used. Imprinting is a genetic phenomena in which an allele is expressed when

inherited from one parent, but is not expressed when inherited from the other parent. Paternal imprinting describes the situation when an allele is expressed only when it is inherited from the father, whereas maternal imprinting occurs when the allele is expressed only when inherited from the mother. Partial imprinting occurred for a gene on C18 affecting number born alive (P < 0.05) and for a gene on C3 affecting age at puberty (P < 0.05). Evidence existed for paternal imprinting of a gene on C10 affecting nipple number and for maternal imprinting of a gene on C1 affecting birth weight and a gene on C4 affecting weaning weight (P < 0.10). Knowledge of imprinting could be used to more effectively develop the parental lines used to produce F₁ females. Selection within maternal sire lines should increase the frequency of beneficial paternally and partially imprinted QTL affecting litter size, nipple number, and age at puberty. Selection within sire lines should also increase the frequency of beneficial maternally imprinted QTL affecting birth and weaning weight in

**Table 1. Generation 10 means for Nebraska Index (I) and Control (C) lines.**

Line	Ovulation rate	Number of fully formed pigs per litter	Number of live pigs live per litter	Age at puberty, days	Nipple number
C	13.80	9.51	9.15	182	14.8
I	20.44	12.58	10.74	192	14.8

Table 2. Calculations of additive, dominance, paternal and maternal imprinting coefficients^a.

Additive Coefficient	=	$1/2 (P_{CC} - P_{II})$
Dominance Coefficient	=	$P_{CI} + P_{IC}$
Paternal Coefficient	=	$(P_{CC} + P_{CI}) - (P_{II} + P_{IC})$
Maternal Coefficient	=	$(P_{CC} + P_{IC}) - (P_{II} + P_{CI})$

^aProbabilities for calculations were defined as:

P_{II} is probability of paternal allele from Line I and maternal allele from Line I,
 P_{IC} is probability of paternal allele from Line I and maternal allele from Line C,
 P_{CI} is probability of paternal allele from Line C and maternal allele from Line I, and
 P_{CC} is probability of paternal allele from Line C and maternal allele from Line C.

grand-progeny. Selection within maternal dam lines should increase the frequency of beneficial maternally imprinted QTL affecting litter size, age at puberty, birth and weaning weights. F₁ gilts produced from the crossing of these two lines should produce larger litters, have greater number of nipples, reach puberty sooner and produce heavier pigs at birth and weaning.

Introduction

Identification of major genes affecting economic traits is an important research goal in the field of animal genetics. Knowledge of effects of major genes can be used to enhance selection response and more effectively design breeding systems using specialized sire and dam lines.

Previous research with an F₂ resource population produced by crossing the Nebraska Index and Control lines identified one QTL affecting ovulation rate, one QTL affecting number of fully formed fetuses, one QTL affecting number of pigs born alive, two QTL affecting number of stillborn pigs, five QTL affecting nipple number, and six QTL affecting age at puberty. Birth and weaning weights were not included in that analysis nor

were parent-of-origin (or imprinting) effects tested. The objective of this study was to use these same data with a sequential statistical procedure and test for imprinting effects to identify additional genomic regions that affect reproductive traits, individual birth weight, and weaning weight.

Methods

Population

A base composite population of Large White and Landrace was formed in 1979. After three generations of random mating, the Nebraska Index Line (Line I) and Control Line (Line C) were established. Line I was selected for an index of ovulation rate and embryonic survival to increase litter size. Line C was randomly selected. The phenotypic means after 10 generations are presented in Table 1.

At Generation 10, pigs were sampled from both lines to create an F₂ resource population. From Line C, 14 gilts and four boars were chosen. From Line I, 12 gilts and five boars were selected. Reciprocal crossing among lines was used to create the F₁. A total of 428 F₂ gilts from three replicates were used in this study.

Data

At birth, number of nipples and birth weight were recorded for all pigs. Weaning weight was recorded at approximately 12 days of age. At 130 days of age, estrus detection was done until gilts showed a second estrus, recording the date of pubertal estrus. In Replicates 2 and 3, gilts underwent laparotomy between 7 and 14 days following second estrus to count number of corpora lutea to measure ovulation rate. Gilts were naturally mated to crossbred boars from another population. At parturition, number of fully formed, live, stillborn and mummified pigs were recorded. In Replicate 1, sows were slaughtered between 7 and 14 days after expression of post-weaning estrus and ovaries were collected and dissected to measure ovulation rate.

White blood cells, liver tissues, and tail tissues were collected from grandparents, F₁, and F₂ pigs and DNA was extracted from these tissues. Each pig was genotyped for 151 molecular DNA markers spanning all chromosomes.

Genetic Probabilities

Pedigree genotypes and estimated genetic distances between markers were used to calculate the probabilities that a particular allele was inherited from each line. These probabilities were then used in QTL analyses. Estimated genetic distances were converted to recombination fractions, the probability of a crossover between any pair of markers. Four probabilities of inheriting the paternal allele from a specific line (I or C) and inheriting the maternal allele from a specific line (I or C) were calculated (i.e., Prob[Paternal = Line I, Maternal = Line C] = P_{IC}). Genetic coefficients (additive, dominance, paternal imprinting and maternal imprinting) were calculated from contrasts of the four probabilities and are illustrated in Table 2.

(Continued on next page)



All traits were analyzed by least squares. Birth weight was adjusted for number of fully formed pigs in the litter in which pigs were born and weaning weight was adjusted for number of pigs at weaning in the nurse litter and for age at weaning. At each position on every chromosome, a schedule of statistical model comparisons was completed (See Figure 1.). Models were compared by calculations of LOD scores. Rejection levels were obtained from 475 permutations of the data. Permutations randomly shuffle the data to estimate how likely an event would occur if the observations had random associations with the molecular information.

Results and Discussion

Analyses with a single QTL model produced suggestive evidence ($P < 0.10$) for QTL affecting birth weight on chromosomes (C) 8 and 12. The additive effects of the allele inherited from Line C were estimated to be $-20 \pm 17g$ and $-59 \pm 19g$ and dominance effects were $85 \pm 31g$ and $-73 \pm 37g$ for the QTL on C8 and C12, respectively. The additive effect of the QTL on C8 is explained as individuals that had both alleles from the control line averaged 20g less birth weight than individuals with two alleles from the Index line. The dominance effect is explained as individuals receiving a C8 allele from each line averaged greater birth weights (by 85g) than the mean of homozygous individuals. The increased inbreeding that occurred in both parental lines likely increased the frequency of homozygotes, decreasing the average birth weight within lines. Crossing increased heterozygosity and resulted in an advantage for pigs that inherited an allele from each line. The negative additive effect on C12 is explained as individuals receiving both alleles from Line C having lower birth weight

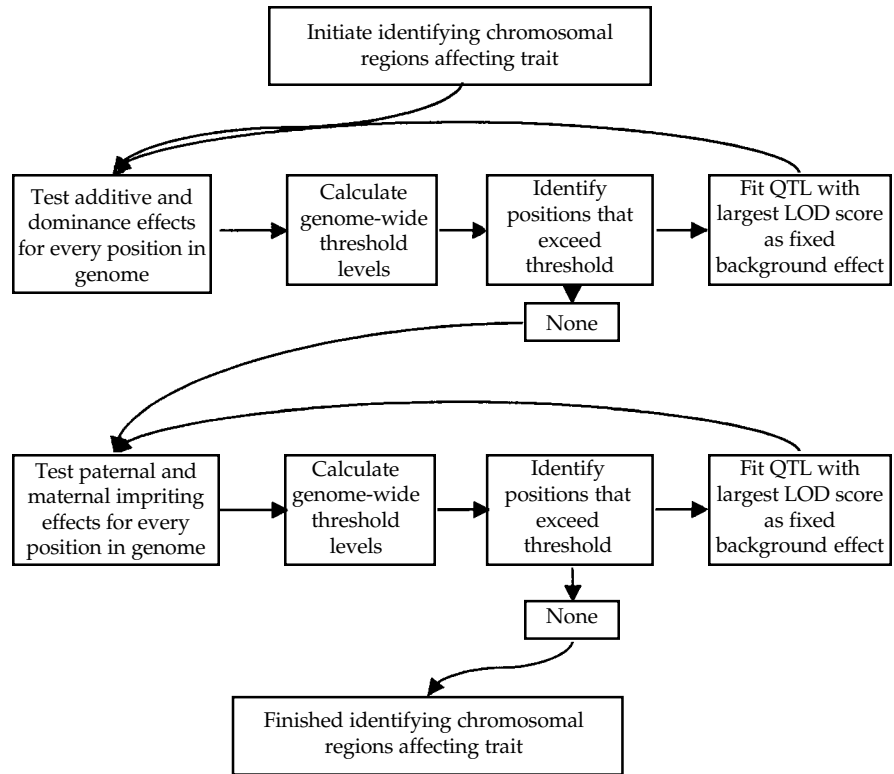


Figure 1. Schedule of model comparisons.

than individuals receiving both alleles from Line I. Although mean birth weight of Line I was less than Line C, Line I possessed alleles that increased birth weight compared with Line C. No QTL were detected for weaning weight.

Quantitative trait loci identified from the sequential statistical procedure are reported in Table 3. Evidence for an additional QTL affecting number of stillborn pigs was found on C12. An additional QTL affecting number of fully formed pigs was found on C6, and two additional QTL for OR on C15 and C8 were identified. No additional QTL were found for number born alive, nipple number, age at puberty, or birth weight.

Imprinted regions, LOD scores and estimates of imprinting effects are presented in Table 4. There was evidence of imprinting for number born alive ($P < 0.05$) on C18, age at puberty ($P < 0.05$) on C3, nipple number ($P < 0.10$) on C10, birth weight ($P < 0.10$) on C1 and wean-

ing weight ($P < 0.10$) on C4.

Imprinting effects occur when an allele inherited from the sire is expressed differently than when the same allele is inherited from the dam. In the case of paternal imprinting, alleles inherited from the sires will have different effects on a trait and the same alleles inherited from the dam will not have any effect on a trait. Paternal imprinting for a gene on C10 affecting nipple number was detected. On average, inheriting an allele from a Line C sire (CC or CI) compared with an allele from a Line I sire (II or IC) resulted in 0.07 ± 0.04 fewer functional teats. There was no detectable difference between alleles inherited from the dams.

For maternal imprinting, alleles inherited from the dams will have different effects on a trait and the alleles inherited from the sire will not have any effect. There was evidence of maternal imprinting for a gene on C1 affecting birth weight and for a gene on C4 affecting wean-



Table 3. Chromosomal regions and estimation of effects by sequentially fitting additional QTL to the model.

Trait ^a	Order ^b	C ^c	cM ^d	Flanking Marker 1	Flanking Marker 2	LOD ^e	a ^f	d ^f
NSB	1	13	101	SW1056	SW38	4.07**	-0.26 ± 0.12	-0.51 ± 0.21
NSB	2	12	60	SW874	S0090	2.58**	0.08 ± 0.13	-0.19 ± 0.22
FF	1	11	52	SW151	SW435	2.80**	-0.11 ± 0.24	-0.40 ± 0.43
FF	2	6	108	SW122	SW2173	2.91**	-0.49 ± 0.22	-0.39 ± 0.34
OR	1	9	1	SW21	S0024	2.64**	-0.25 ± 0.21	0.49 ± 0.36
OR	2	15	48	SW1989	SW1945	2.89**	0.15 ± 0.24	-0.57 ± 0.37
OR	3	8	20	SY23	SW905	2.57*	0.23 ± 0.26	-1.58 ± 0.47

^aNSB = number of stillborn pigs; FF = number of fully formed pigs; OR = ovulation rate.

^bOrder that QTL were added to the model.

^cChromosome number.

^dRelative position in Kosambi centimorgans.

^eLOD score corresponding to entry into model.

^fEffect estimated using full model with appropriate QTL and imprinting effects in units of pigs for litter traits and corpora luteum for ovulation rate.

* Genome-wide significance threshold of $P < 0.10$.

** Genome-wide significance threshold of $P < 0.05$.

Table 4. Results from fitting a model with imprinting.

Trait ^a	C ^b	cM ^c	Flanking Marker 1	Flanking Marker 2	LOD ^d	p ^e	m ^e
NBA	18	25	SW1984	SW787	3.48**	0.34 ± 0.11	-0.37 ± 0.10
AP	3	71	SW2047	S0002	3.51**	3.44 ± 1.10	-2.95 ± 1.03
NN	10	75	SW1991	SW951	2.81*	-0.07 ± 0.04	NA
BWT	1	91	SW952	SW307	2.88*	NA	-3.25 ± 0.91
WWT	4	149	SW445	MP77	2.94*	NA	7.67 ± 2.25

^aNBA = number born alive; AP = age at puberty; NN = nipple number; BWT = individual pig birth weight; WWT = individual pig weaning weight.

^cChromosome number.

^dRelative position in Kosambi centimorgans.

^eLOD score corresponding to presence of imprinting effects.

^fImprinting effect estimated using a model with appropriate significant QTL in units of pigs for litter traits, days for age at puberty, nipples for nipple number, and grams for weight traits.

* Genome-wide significance threshold of $P < 0.10$.

** Genome-wide significance threshold of $P < 0.05$.

ing weight. On C1, piglets with maternally inherited Line C alleles (CC or IC) averaged lower birth weights than pigs with maternally inherited Line I alleles (II or CI). Although Line C piglets had larger birth weights than Line I, this QTL can only partially offset the effects of other genes that caused increased birth weight in Line C. Piglets with maternally inherited Line C alleles averaged greater weaning weights than those with maternally inherited Line I alleles. A possible explanation may be that as litter size increased with selection, the energy requirements for lactating sows also increased. There may have been a selection advantage in Line I for maternal alleles that decreased or maintained energy requirements for lactating sows with the potential for more pigs per litter. Decreased pig survival to wean-

ing and decreased number weaned in Line I may have been affected by this QTL.

Partial imprinting occurs when maternal and paternal imprinting are simultaneously affecting a trait. In this case, the largest difference is between the two heterozygotes (CI vs. IC). Partial imprinting of QTL on C18 affecting number born alive was detected. On average, inheriting Line C alleles from the sire (CC or CI) increased number born alive compared with Line I alleles (IC or II). Inheritance of Line I alleles from the dam (II or CI) also increased number born alive by 0.37 ± 0.10 pigs per litter compared with Line C alleles (CC or IC). On average, receiving the Line C allele from the sire and the Line I allele from the dam (CI) resulted in approximately 0.7 more live pigs per litter than the reciprocal heterozygote (IC). In

addition, evidence for partial imprinting for a QTL on C3 affecting age at puberty between markers SW2047 and S0002 was found. On average, daughters receiving Line C alleles from sires were delayed in puberty compared with gilts receiving Line I alleles. In contrast, gilts receiving Line C alleles from their dam reached puberty sooner than daughters inheriting Line I alleles from their dam.

Although chromosomal regions have been identified that affect reproduction and early pig weights, the exact genes causing these effects are still unknown. Further research is needed to identify these genes.

¹J. W. Holl is a graduate student and R. K. Johnson is a professor in the Department of Animal Science.



Role of the Gonadotropin-Releasing Hormone (GnRH) Receptor in Determination of Ovulation Rate Between Lines of Swine

Benjamin E. Bass
Ginger A. Mills
Brett R. White¹

Summary and Implications

Litter size plays a major role in the economics of swine production. Even modest increases in average litter size can have considerable effects on overall profitability. Two major components of litter size, 1) ovulation rate, and 2) embryonic survival, have been used in a selection index project ongoing for several generations at the University of Nebraska-Lincoln (UNL). To better understand the mechanisms of one component, ovulation rate, we are investigating the role of the gonadotropin-releasing hormone (GnRH) receptor in determination of this important trait. Although other factors may influence determination of ovulation rate, this receptor has an established physiological importance to the processes comprising ovulation rate, recruitment of follicles and regulation of ovulation. In addition, the GnRH receptor gene is located near a chromosomal marker for ovulation rate in the pig, providing a genetic rationale to study this receptor. Recently, the sequence for the porcine GnRH receptor gene has been determined, allowing comparisons between lines of pigs divergent for ovulation rate. Identification of unique genetic changes in swine strains with increased ovulation rates, such as the Chinese Meishan and the index selection line at UNL, may allow for a better understanding of prolificacy. This critical information may also be utilized to enhance litter size in other lines of pigs and improve efficiency of pig production.

Background

Prolificacy is an important measure of productivity in the swine industry, representing an economically important trait. Two primary components of litter size are ovulation rate and uterine capacity. While uterine capacity is a critical component, it is hard to quantify and difficult to select for. Ovulation rate, on the other hand, can be improved in a number of different ways including nutrition (flushing) and hormonal treatment. However, there is very little known about the mechanisms behind increased ovulation rate.

Ovulation rate is influenced by circulating levels of follicle stimulating hormone (FSH) and luteinizing hormone (LH), also known as the gonadotropins. The production

of these hormones is controlled by the reproductive axis (Figure 1), consisting of the hypothalamus, anterior pituitary gland and gonads (ovaries or testes). Specifically, gonadotropin-releasing hormone (GnRH) is released from the hypothalamus and binds to its receptor on gonadotrope cells of the anterior pituitary gland. Upon binding to its receptor, GnRH stimulates the expression of the genes that lead to the production of FSH and LH, as well as the GnRH receptor itself. The secreted gonadotropins then act on the ovaries to recruit follicles (FSH) or induce ovulation (LH). Steroids, produced by the ovaries, such as estrogen and progesterone provide feedback at the level of both the anterior pituitary gland and hypothalamus to regulate subsequent gonadotropin production.

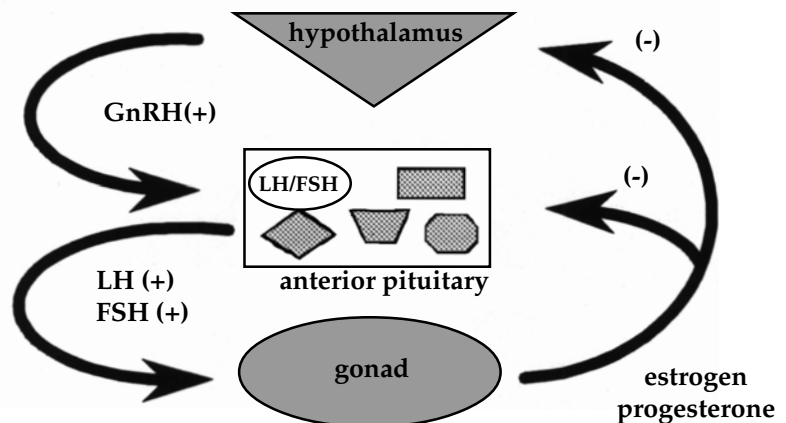


Figure 1. The Reproductive Axis. Gonadotropin-releasing hormone (GnRH) is released from the hypothalamus and binds to its receptor on gonadotrope cells of the anterior pituitary gland. The binding of GnRH to its receptor causes production and secretion of the gonadotropins, follicle-stimulating hormone (FSH) and luteinizing hormone (LH). Both FSH and LH travel through the blood and act on the gonads. Steroid hormones produced by the gonads provide feedback to both the hypothalamus and anterior pituitary gland, regulating further GnRH, LH, and FSH secretion.

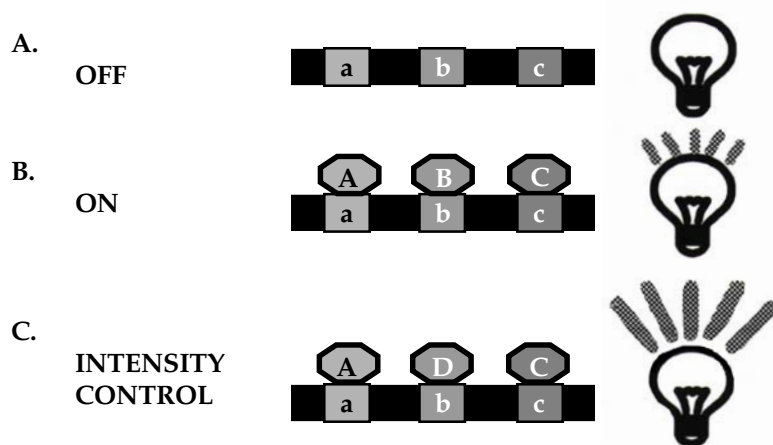


Figure 2. Regulation of gene expression. Inactivated gene (A), activated gene (B), activated gene with increased intensity (C).

Therefore, reproductive function is highly dependent on the interaction of GnRH and its receptor.

Sensitivity or number of GnRH receptors present on the anterior pituitary gland may stimulate higher levels of gonadotropin production in lines of swine with increased ovulation rates. There is evidence that elevated amounts of gonadotropins may contribute to determination of ovulation rate. Previous studies at the University of Nebraska-Lincoln (UNL) indicated that concentrations of both FSH and LH were elevated in lines of swine with increased ovulation rates (17 to 26) when compared to control lines (12 to 16). Levels of FSH could aid in determination of ovulation rate via: 1) enhanced recruitment of follicles during development, 2) decreased follicular atresia (death) during the luteal phase, or 3) increased selection during the beginning of the follicular phase. According to researchers at the Agricultural Research Service of the United States Department of Agriculture (USDA), an FSH surge following ovulation increased small follicle (<4 mm in diameter) populations in pigs, indicating FSH may be involved in early follicular recruitment at the start of the estrous cycle. In contrast, higher ovulation rates may be a result of prolonged exposure to FSH during follicular recruitment. Exposure to increased concentrations of FSH

during the estrous cycle may improve both the viability and number of recruited follicles.

Although all of the human and mouse genes have been identified and the information made available, many of the porcine genes remain to be identified. Recently, the entire sequence for the porcine GnRH receptor gene was reported by researchers at the University of Guelph. Upon isolation of the gene, investigators at the USDA Meat Animal Research Center, have determined that it is uniquely located in a similar region as a chromosomal marker for ovulation rate. Therefore, the GnRH receptor gene is both a physiological and positional candidate for genes influencing ovulation rate in swine. This sequence allows for isolation and quantification of GnRH receptor gene expression, so comparisons can be made between lines of pigs with ovulation rate differences. Furthermore, scientists can also look for differences in the regulatory region of the gene between lines of swine with increased ovulation rates and their contemporaries. The regulatory region dictates the activation and intensity of gene expression. Regulation of gene expression can be compared to an adjustable light switch (Figure 2). If the correct components are unavailable, the gene is turned off, or inactivated (Panel A). When those components become available (Panel B), the gene is turned

on, or activated. Finally, a different combination of components, such as those produced following hormonal stimulation, can increase the intensity of gene expression (Panel C).

Several differences have been reported within the regulatory region of the GnRH receptor gene between Chinese Meishan and white crossbred pigs by researchers at the University of Guelph. Females of the Chinese Meishan breed have a higher ovulation rate than occidental breeds, resulting in four to five more piglets per litter. Thus, Meishan pigs may harbor genetic differences with the potential to enhance the reproductive performance of white crossbred pigs. Consistent with the Meishan model, researchers at UNL have developed a line of pigs that was selected 11 generations for an index of ovulation rate and embryonic survival and nine more generations for increased litter size. At generation 14 the UNL index selection line of white crossbred pigs ovulated 7.4 more eggs and produced 1.1 more live born piglets per litter than unselected, control animals. Classically, genetic improvements have been accomplished by selection for desirable traits. However, genetic change per generation in each trait may be small. Identification of a gene that could be easily screened and that is correlated with ovulation rate in young animals would be of great interest for selection purposes. Given the physiological relevance and chromosomal location of the GnRH receptor gene, it may represent a potential marker to identify females with a genetic capacity to produce larger litter sizes.

Preliminary Data

Current experiments being carried out in our laboratory seek to identify differences in production of GnRH receptors between lines of swine with improved ovulation rates and standard lines. Of

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interest to us are differences in GnRH receptor gene expression, number of receptors available to bind GnRH and the affinity (attraction) of those receptors to GnRH. Our laboratory has isolated and sequenced approximately 5000 base pairs of the regulatory region for the GnRH receptor gene. Work is now underway to characterize the regulatory region of the GnRH receptor gene and identify segments of this region that promote differences in expression between lines of swine. Finally, we would like to understand how hormones, such as GnRH and estrogen, are involved in the regulation of GnRH receptors.

Implications

Determination of ovulation rate is very important to swine production, as it is a component of litter size. A modest increase in average litter size of 0.2 pigs per litter on a 10,000 sow operation could net a producer nearly \$99,000 in additional profit, depending on pork prices. If differences in non- or hormonally-stimulated GnRH receptor gene expression levels between Meishan, Index, and Control lines are determined, a region of the gene may be isolated to provide a genetic test for ovulation rate. Ultimately, the unique genes from

individuals with increased ovulation rates could be incorporated into transgenic swine. This would allow the opportunity to increase ovulation rate in any breed or line of pigs, while maintaining the beneficial characteristics of that breed or line. These animals would be very valuable to pork production worldwide.

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Thermal Conditions Within Pens Fitted With Differing Zone-Heating Options and Resulting Performance of Newly Weaned Pigs in a Wean-to-Finish Facility

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Summary and Implications

Research was conducted to assess the effects of the type of zone heater and floor mat used in a wean-to-finish building on the thermal environment created for newly weaned pigs and resulting pig performance. Gas-fired brooder heaters were compared to electric heat lamps and farm-cut wood sheathing was compared to commercial [unheated] rubber floor mats. No consistent differences in air temperature near the heating zone were found between either of the treatments. However, black-globe temperatures in pens having gas-fired heaters and/or wood mats were consistently warmer than in their comparison pens. Temperature deviations during the 26-day study period were similar statistically for both air and

black-globe temperatures (about $\pm 2.5^{\circ}\text{F}$) for all treatments, as were the temperature deviations from pen to pen for all treatment combinations ($\pm 1.7^{\circ}\text{F}$ or less). Pig health was affected by an outbreak of porcine reproductive and respiratory syndrome (PRRSV). Performance of the disease-challenged pigs was similar for the two heating systems. However, pigs in pens having wood sheathing on the floor below the zone heater consumed more feed on a daily basis than those resting on rubber mats. This evidence supports statistically significant ($P < 0.05$) advantages for the wood mats in pig weight (+3%) and average daily gain (+6%) over the 26-day study period. Feed-to-gain ratios over this same time period were similar for all treatments. The fact that there was greater radiant heating (as indicated by warmer black-globe temperatures) with gas-fired heaters in this study suggests that extra adjustments in heater height and gas pressure may have been needed to obtain equivalent

heating effects, and that additional information on placement and adjustment of zone heaters also would be useful to producers. The data collected in this study and associated experience of farm management imply that producers can develop a similarly stable thermal environment for nursery pigs using either electric heat lamps or gas-fired brooder heaters. The improved heating effect and pig performance observed in this study with floor mats made from wood sheathing have positive practical implications. Sheets of wood sheathing are readily available from many local lumber suppliers and hardware stores and can be purchased at a fraction of the price of commercial rubber mats. A small amount of labor is required to quarter the sheets, and we don't recommend re-using the wood mats. But, the results of this study suggest that wood sheathing should be investigated further as a floor-mat option.

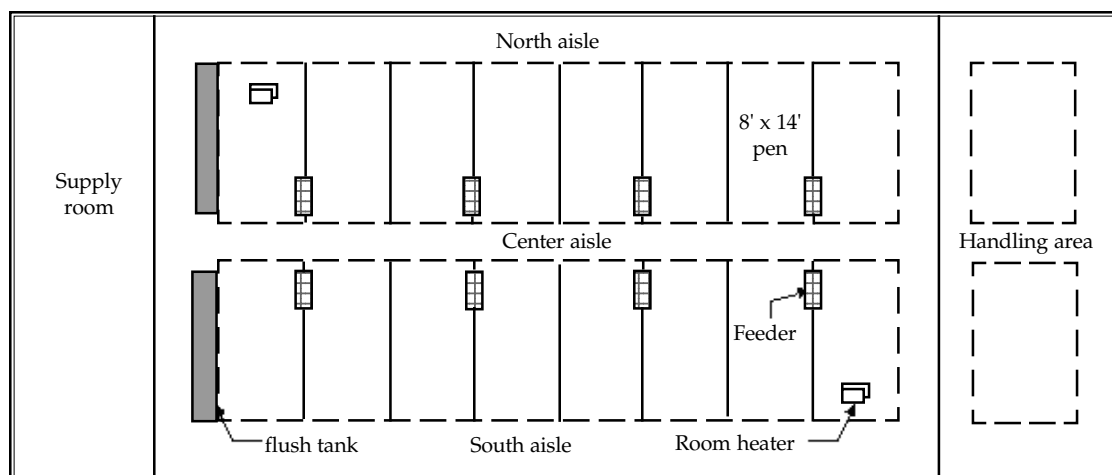


Figure 1. Layout of the wean-to-finish facility used in this study.

Introduction

While wean-to-finish systems are rapidly gaining in use, the development of useful information on the appropriate selection of zone-heating components has not kept pace. The advantages of wean-to-finish production systems rest mainly in moving pigs one less time during production, which results in less stress on the pigs and reduced labor associated with moving pigs from a nursery unit to the grow-finish facility. Improved profit potential depends largely on performance soon after pigs are placed in the wean-to-finish facility—when the newly weaned pigs are placed in a facility designed to accommodate much larger market-weight hogs. This research project addressed the issue of providing a comfortable thermal environment in a cost-effective manner, which, along with overcoming inefficient space utilization and limiting the incidence of gastro-intestinal disease when pigs are small, is a major determinant of profitable production.

Materials and Methods

The research project was conducted in a wean-to-finish facility (see Figure 1 for facility layout) at the Haskell Agricultural Laboratory in Concord, Neb., during early

spring, 2003. The performance of two heat sources (brooder heater vs. heat lamp) and two floor mats (wood sheathing vs. rubber) was compared in a 2x2 factorial arrangement of treatments. The 16 available pens at the wean-to-finish facility allowed the replication of each treatment combination in four pens.

Gas-burning brooder heaters (Gasolec2 M3 LP 20-310 Infrared Heater, Gasolec America, Inc., Tulsa, Okla.) with a maximum rated output of 5,425 Btu/hr (1,590 W) were installed in September 2002 along with necessary gas distribution lines and fixtures. Room temperature was maintained using two unvented propane heaters in the northwest and southeast quadrants of the room (Figure 1). A gas meter was installed to record propane usage of the gas-fired zone heaters. These heaters were operated with newly weaned pigs during a pre-trial fall finishing phase to ensure that the equipment was operable and functioned as desired with the modulating controller. This test period also allowed the herdsman and farm management to become as comfortable using the new heat sources as they were using electric (250 W) heat lamps.

After this group of hogs was removed (sent to market), the facility was cleaned according to standard procedures on the research farm. Then, commercial rubber floor

mats and mats made of 3/8 inch OSB (oriented-strand board) sheathing were placed in randomly assigned treatment pens for the new batch of weaned pigs. The wood mats were cut to the same dimensions (42 x 42 inches) as the commercial rubber mats. Correspondingly, gas-fired heaters were removed from eight randomly assigned pens and were replaced with electric heat lamps, so each heater/mat combination was replicated within four pens (Figures 2-3).

Newly weaned 17-day-old pigs were placed within pens at a stocking rate of 15 pigs per pen (7.5 sq ft/pig). Each pen had one two-hole FarmWeld wean-to-finish feeder and one wean-to-finish cup waterer. Pigs were weighed weekly for the first four weeks post-weaning. The original intention was to weigh pigs biweekly thereafter to slaughter weight, but when PRRSV (Porcine Reproductive and Respiratory Syndrome) was diagnosed in the pigs during the second week after placement in the facility, these plans were altered. The pigs were uniformly medicated and monitored. About two weeks later, the pigs reached a size where zone heat was no longer required (based upon farm management criteria). At this point, 26 days after the newly weaned pigs entered the facility, zone heat-

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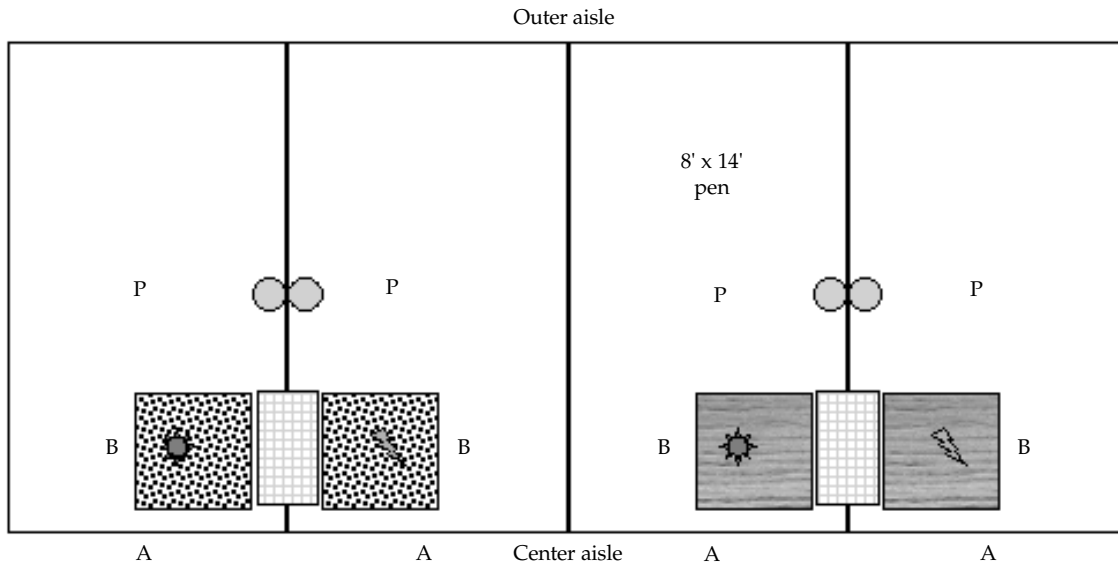
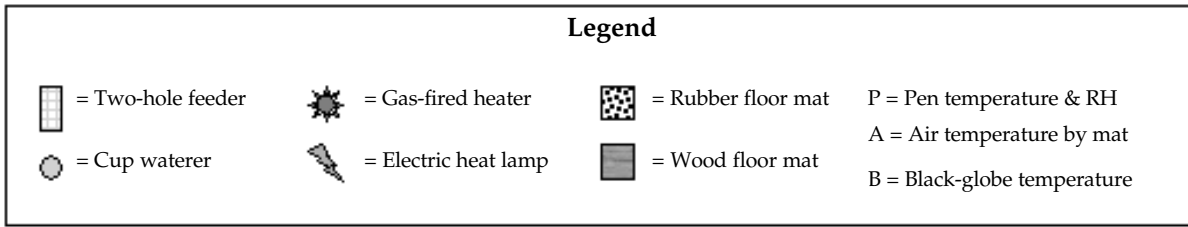


Figure 2. Pen layout showing key pen features, the four combinations of heaters and mats used in this study, and locations of sensors within pens.

ing was discontinued simultaneously in all of the treatment pens and the experiment was terminated.

Thermocouples were placed in each pen to measure air temperature and black-globe temperature near the floor mat (resting area with zone heat). Air temperature in each pen was measured just outside of the aisle pen gate, near the middle of the pen floor mat and about 1 foot above the floor. Black globes were situated inside the pens, consistently placed along the side of the mat opposite the feeder and a little less than two feet off the pen floor. Measurement of 'black-globe temperature' directly incorporates the effect of radiant heating — the type of heating performed by both zone-heating systems. These temperatures were measured at 1-minute intervals and data loggers recorded average temperatures every 10 minutes. Additionally, miniature recorders were placed centrally within each pen and 5-6 feet off the floor to record air tem-

perature and humidity — again at 10-minute intervals. Weather data for the research station during the study period was collected and retrieved to help qualify observed

heating needs. Data on pig performance and environmental temperatures were analyzed as a complete random design with pen as the experimental unit.



Figure 3. Photo of two of the four treatment combinations used - an electric heat lamp and wood mat (left-hand pen), and a gas-fired heater and rubber mat (right-hand pen).

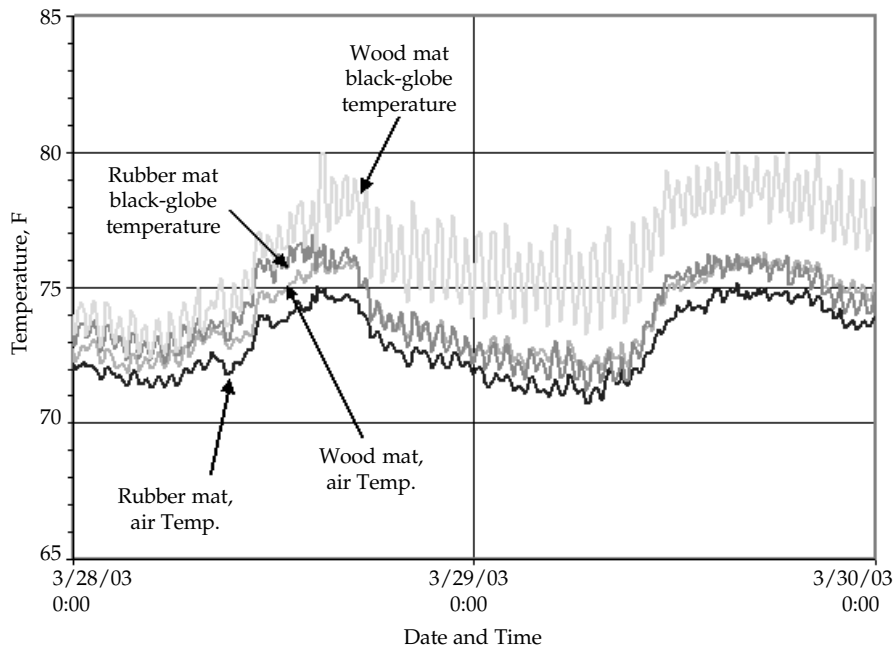


Figure 4. Air and black-globe temperatures near the zone-heating area over a two-day period, illustrating average temperatures for pens having rubber vs. wood floor mats.

Results and Discussion

The data obtained for this study were derived over the first 26 days of the wean-to-finish growth period [March 15 to April 9, 2003], rather than over the full time from weaning to market weight, due to PRRSV being diagnosed during week 2. The newly weaned pigs entered the facility weighing 11.4 lb and were removed weighing about 25 pounds. Zone heat was available throughout this 26-day period, with pigs taking advantage of it extensively during the first two weeks.

Temperature

Air temperatures inside the facility fluctuated over the 26 days, as would normally occur in production facilities, but not nearly as much as the temperature outdoors. In the ideal environment, the temperature is always the same as the set-point temperature. In practice, producers want to develop a stable environment with minimal fluctuation. The average heating zone air temperature (at the aisle sides of the pens next to the floor mats) was about 74.5°F, with the coolest pen

(southeast quadrant, electric lamp, rubber mat) averaging 72.8°F and the warmest (northwest, gas, wood) 76.9°F. The standard deviation about the mean, representing the fluctuation in zone air temperatures over time, was about $\pm 2.8^\circ\text{F}$ overall, with the fluctuation within the most consistent pen (northeast, gas, wood) being $\pm 2.12^\circ\text{F}$ compared to $\pm 3.22^\circ\text{F}$ in the most variable pen (northwest, gas, wood). One of the room heaters was located next to the most variable pen, which may have influenced the amount of fluctuation observed in that pen. There were no statistical differences between treatments or treatment combinations in terms of level of temperature fluctuation, with roughly $\pm 2.4^\circ\text{F}$ fluctuations observed over time for the treatments. For comparison, the average outdoor air temperature during the same period was 44.2°F with a standard deviation of $\pm 14.14^\circ\text{F}$.

Black-globe temperatures inside of the pens (next to the floor mats) were maintained around 76°F with the coolest pen (northwest, gas, rubber) averaging 74.1°F and the warmest (northwest, gas, wood) 80.7°F. The standard deviation about

the mean globe temperature over time was about $\pm 3.0^\circ\text{F}$ with the fluctuation in the most consistent pen (southwest, electric, wood) being $\pm 1.75^\circ\text{F}$ compared to $\pm 2.97^\circ\text{F}$ in the most variable pen (northwest, gas, wood). There were no statistical differences between treatments or treatment combinations in terms of level of fluctuation in black-globe temperature, with roughly $\pm 2.4^\circ\text{F}$ fluctuations again observed over time for the treatments. The temperature variations observed in this study highlight the challenge that producers face when trying to develop stable zone-heating environments for small pigs.

Temperature differences between treatments and between sides of the facility are shown in Table 1 alongside the average standard deviation in temperatures across pens within the respective treatments/sides. The latter number represents how much variation there was between the replications of similar treatments and treatment combinations. A difference in temperature between treatments is noteworthy if it is large relative to the variation within treatments.

Overall, air temperatures were slightly warmer in pens with gas-fired heaters and in pens with wood mats. However, no temperature difference exceeded the corresponding temperature deviation within treatments, and in only one case was a difference in air temperature between treatments greater than 1°F. Consequently, there were no statistically significant differences in air temperature between treatments or treatment combinations.

Larger differences and a wider range of standard deviations were evident for black-globe temperature. The black-globe temperatures within pens having gas-fired heaters and wood mats were notably higher (about 3°F warmer) on average than within their counterpart pens with electric heat lamps and/or rubber mats (Figure 4). These differences were at least twice that

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of the corresponding variation within treatments. Consequently, statistically significant differences in black-globe temperatures existed between both treatments and amongst the treatment combinations. Interestingly, the largest differences in black-globe temperatures corresponded with the smallest differences in air temperature, illustrating that the two sensors measured different thermal effects. Black-globe temperature directly incorporates the effect of radiant heating, whereas air temperature does not. Since zone heaters rely heavily on radiant heating, it makes sense that any temperature differences between treatments would show up more prominently in the black-globe temperatures. The higher black-globe temperatures with gas-fired heaters may suggest an actual difference in heating effect or it may imply that extra adjustments in heater height and gas pressure were needed to obtain equivalent heating effects. The higher black-globe temperatures with wood floor mats most likely are due to wood having different surface characteristics (e.g. reflectivity) than rubber. A soon-to-be-completed analysis of manual mat and pig surface temperature readings may allow a more complete assessment of heating effects.

The zone heaters were managed with the intent of maintaining consistently comfortable thermal conditions in each pen (based upon operator observations and experience). The fact that standard deviations in air and black-globe temperatures within treatments were relatively low suggests that farm management was able to produce similar thermal environments within similar zone-heating treatments.

Differences in temperatures between the north and south sides and the east and west halves of the facility were noticeably small, which suggests that location effects were minimal in the research facility. Since the air temperature sensors were

Table 1. Temperature differences (zone-heating areas) for the treatments and average temperature deviations within the compared treatments.

Treatment comparison	Air temperature		Black-globe temperature	
	Temperature difference (°F)	Temperature deviation, StD. (°F)	Temperature difference (°F)	Temperature deviation, StD. (°F)
Gas-fired vs. electric heater	0.91	1.46	*2.07	1.53
- in pens w/wood mats	0.81	1.46	**3.35	1.28
- in pens w/rubber mats	1.06	1.44	**0.70	1.01
Wood vs. rubber mat	0.69	1.51	*1.76	1.69
- in pens w/gas heaters	0.59	1.65	**2.94	1.46
- in pens w/electric heaters	0.83	1.25	*0.29	0.83
North vs. south pens	-0.16	1.54	-0.01	1.85
East vs. west pens	0.10	1.53	-0.24	1.97

*Indicates that the treatment difference was statistically significant at $P < 0.05$.

**Indicates that a statistically significant ($P < 0.05$) interaction effect existed overall between type of heat source and floor mat used.

Table 2. Pig performance over 26-day trial period for experimental treatments.

Treatment	Final weight (lb)	CV within pen (%)	ADF (lb)	ADG (lb)	Feed:Gain
Heat source					
Gas-fired heater	25.2	20.6	0.73	0.53	1.37
Electric heat lamp	24.9	18.6	0.75	0.52	1.44
Floor mat					
Wood mat	*25.4	20.1	0.76	*0.54	1.40
Rubber mat	24.7	19.0	0.72	0.51	1.41

*Indicates that the treatment advantage was statistically significant at $P < 0.05$.

all located in the 5-foot-wide central aisle, those on the north side were only about 5 feet away from those on the south side, and very little temperature difference was expected. Air temperatures tended to be coolest in the northwest pens, which makes sense given the prevalence of cold-season winds from the north and northwest in northeast Nebraska and the resulting increase in heat loss from exposed building surfaces.

Pig Performance

Results for pig performance at the end of the trial - 26 days after placement in the facility when zone heating was discontinued — are shown in Table 2. The pig-performance results describe effects on nursery-age, disease-challenged pigs raised in a wean-to-finish facility. Since the PRRSV outbreak and symptoms existed in all pens, and treatment was uniformly applied, the results were considered statistically valid with health

status being a confounding factor.

No statistically significant differences in pig performance were found between pigs raised in pens with gas-fired heaters vs. electric heat lamps. However, pigs raised in pens with wood floor mats outperformed ($P < 0.05$) those on rubber mats in terms of final (26-day) weight and average daily gain (ADG). These differences amounted to 3% and 6% improvements, respectively, over the rubber mats. There was some evidence that average daily feed intake was higher for pigs on wood mats also ($P = 0.14$), which lends additional credence to the findings for pig weight and ADG. There was some evidence that the coefficient of variation in 26-day pig weight may have been higher for pigs in pens with gas-fired heaters ($P = 0.19$); however, there also may have been an interaction between heat source and mat ($P = 0.08$). No other treatment or treatment interaction (heat source x mat) effects on performance were



observed. Time-lapse video recordings will be analyzed to determine whether behavior differences can help explain the performance differences found between the mat types.

Conclusions

The electric heat lamps and gas-fired heaters functioned well and were readily managed during this trial. Analyses of temperature fluctuations revealed that temperatures were generally maintained within $\pm 3^\circ\text{F}$ of the mean temperature, and that there were no differences in temperature fluctuations between the two heating systems, the mat types, or combinations of the treatments. No significant differences in air temperatures were evident between treatments or treatment combinations. Black-globe temperatures within pens with gas-fired heaters and/or wood floor mats were warmer ($2\text{--}3^\circ\text{F}$) than in com-

parison pens having electric heat lamps and/or rubber floor mats. The higher black-globe temperatures with gas-fired heaters may imply that extra adjustments in heater height and gas pressure were needed to obtain equivalent heating effects. Since producers often struggle to find the right setting for their zone heaters, this issue may deserve additional study. Given the variety of farm situations and management practices that exist, information that would help producers calibrate their zone-heating equipment once it is installed would be helpful. Higher black-globe temperatures with wood floor mats most likely were due to wood being more reflective than rubber.

This study showed an advantage to using wood floor mats in terms of pig growth rate (end weight and ADG), at least for nursery-age, disease-challenged pigs. This advantage combined with the ready availability and low cost of wood

sheathing (relative to commercially distributed rubber mats) suggests that producers may have another option to cut costs while enhancing production. This study did not reveal any other significant treatment or interaction effects on performance. A subsequent economic assessment of the heaters and mat types should shed more light on which zone-heating systems should be considered most seriously by producers and under what circumstances.

This research was financially supported by a grant from the National Pork Board per the recommendations of the Nebraska Pork Producers Association.

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Where Can I Build or Expand a Livestock Operation?

A Case Study of Cuming County, Nebraska

Chris Henry
Jeff Arnold¹

Summary and Implications

The impacts that setback distances of 1/4, 3/8, 1/2, 3/4, and 1 mile would have on the land area available to the livestock industry for expansion in Cuming County, Neb. were estimated using a geographic information system and the current county zoning requirements. These setbacks seem to be typical of distances cited in many county zoning regulations. Setback distances greater than 3/8 of a mile appear

to be very exclusive to expansion of the livestock industry in Cuming County. Reciprocal setbacks that apply to new housing construction do not appear to be restrictive. It is expected that other Nebraska counties that are similar in population density will have similar resulting land areas available for livestock facility expansion for similar distances. Setbacks of greater than 1/4 of a mile may substantially retard growth of the livestock industry in a county.

Introduction

The purpose of this work was to evaluate the land available to

livestock producers looking to construct new facilities and to people wishing to build new residences in rural Cuming County, Neb. Cuming County was chosen for several reasons. Records indicating locations of permitted livestock facilities for Cuming County are more up-to-date than those for many other counties, according to Nebraska Department of Environmental Quality (NDEQ). Second, Cuming County has high population densities of both animals and people. Finally, Cuming County has a sliding scale setback requirement: that

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is the larger the facility, the further the setback distance needed, which demonstrates the impact different distances have on land area. Many times setback distances are chosen arbitrarily. Through this analysis we intend to show the impact those decisions have on the actual land area available based on the setback requirements outlined in comprehensive plans.

Population and Density Characteristics of Cuming County

Cuming County has a large concentration of livestock production facilities. General information about population densities of people and housing units from National Agricultural Statistics Service and the U.S. Census Bureau for selected counties in Nebraska are shown in Table 1. These counties are traditionally strong in animal agriculture. The distribution of operations in Nebraska is generally very dense in the eastern one-third of the state.

Cuming County appears to have one of the highest concentrations of AFOs (animal feeding operations) in Nebraska. Also, Cuming County is in the top tier of populated counties in Nebraska, being 27th out of 92 counties, according to the 2000 U.S. Census. The county has a lower population density at 18 persons per square mile compared to neighboring counties, such as Madison (43 persons per square mile) and Colfax (25 persons per square mile). Another measure of person density is housing units. For the counties studied, Cuming County has a relatively low density (8 houses/sq mile) of housing units per unit area, suggesting a very sparsely populated rural community.

Cuming County has a very high concentration of animal units per square mile, perhaps the highest in Nebraska at 539 Animal Units (AU) per square mile. Another measure of density is the ratio of AU to persons. Of the selected counties studied, Cuming County has the highest ratio of AU to persons (30).

Table 1. Comparison of human and livestock populations or densities.

County	Rank (# out of 92)	Population density (persons/square mile)	Housing units/sq mile	Animal units ^a /sq mile	Ratio AU ^a :persons
Boone	51	9	4	189	21
Cuming	27	18	8	539	30
Colfax	26	25	10	323	13
Madison	8	62	25	167	3
Platte	10	47	19	236	5
Dawson	12	24	10	275	11

Source: 1999 NASS and US Census 2000 (results have been rounded to the nearest whole number)
^aAU: Animal Unit, a standard way of representing livestock. An animal unit is standard way of comparing different species and sizes of livestock.

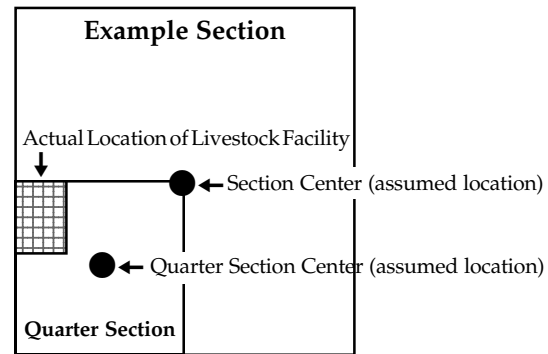


Figure 1. Assumed locations of livestock facilities from legal descriptions.

Method

To evaluate the land area available for livestock to locate in Cuming County, information on land features, such as streams, roads, residences, livestock facilities and groundwater wells was needed. This information was available geographically from state databases and was assembled using GIS (geographic information system) data. From this data, county zoning and NDEQ setback requirements were applied. The result yielded the land area available for locating or expanding a livestock facility and new rural residential construction.

To complete this analysis, information on livestock facility location, resident locations, streams, roads, cities, and setback locations was needed. Livestock facility locations were derived from legal descriptions, so locations of livestock facilities are not exact. The location of the livestock facilities

were placed either the center of the section center, quarter section or quarter-quarter section depending upon the legal description available. Figure 1 shows an example of the spatial precision with which livestock facilities were located.

Title 130, the rules and regulations governing the location of livestock waste control facilities, requires a 100-foot setback from any residential well not owned by the owner of the livestock facility, or for any well used for domestic purposes. To simplify the analysis, it was assumed that anyone locating a livestock facility would not be able to locate it within 100 feet of any registered groundwater well.

After all the data were compiled, a GIS software package (ARCGIS 8.2) was used to establish the setbacks around land features. The only required setback distance from land features was groundwater wells, as per Title 130 mentioned above. Roads were assumed



Table 2. Required setback distances from other land features.

Land feature	Setback distances for livestock facilities	Setback distances used for residential development
Roads (major and minor)	125 feet (all roads)	50 feet minor 100 feet for state or US Hwy.
Streams (major and minor)	100 feet	100 feet
Cities (West Point, Beemer, and Wisner)	1 mile	N/A
Registered groundwater wells	100 feet ^a	N/A

^aRequired by NDEQ to site a new livestock waste control facility.

Table 3. Animal feeding operation setbacks from residences.

Animal Units	Swine under 55 lbs, head	Swine over 55 lbs, head	Setback Distance, mile
Less than 300	< 7,500	< 750	None
301-1,000	<25,000	<2,500	1/4
1,001-5,000	<125,000	<12,500	3/8
5,001-10,000	<250,000	<25,000	1/2
10,001-25,000	<625,000	<62,500	3/4
>25,000	>625,000	>62,500	1

to have a constant setback of 125 feet from the centerline of the road, independent of the type of road. Most new livestock facilities would not locate within 100 feet of a stream, so this setback was applied. A 1-mile setback was applied to the four urban areas in Cuming County. While not required, this seemed a reasonable and common sense

voluntary setback that anyone would observe when locating a new livestock facility. The setback distances evaluated are shown in Table 2.

Similar setback distances from new residences were also evaluated assuming that setbacks would be reciprocal from existing livestock facilities (Table 3). It was assumed

that most homeowners would build closer to roads, yet would not locate with 100 feet of the four major roads in Cuming County. The same setback from streams was observed, based on the assumption that most home owners would stay at least 100 feet from a stream.

The setbacks from all features were applied along with the corresponding setback for each class of livestock facility. Cuming County assigns setbacks based on the size of facility (Table 3).

Results and Discussion

The resulting land excluded from livestock expansion is shown in Table 4. As can be seen, setback requirements greater than 3/4 mile almost completely exclude any new livestock facilities. Even a 1/2-mile setback leaves only about 4% of the county available to new livestock production facilities. A 1/4-mile setback leaves 39% of the county open to siting a new livestock operation, while a 3/8-mile setback

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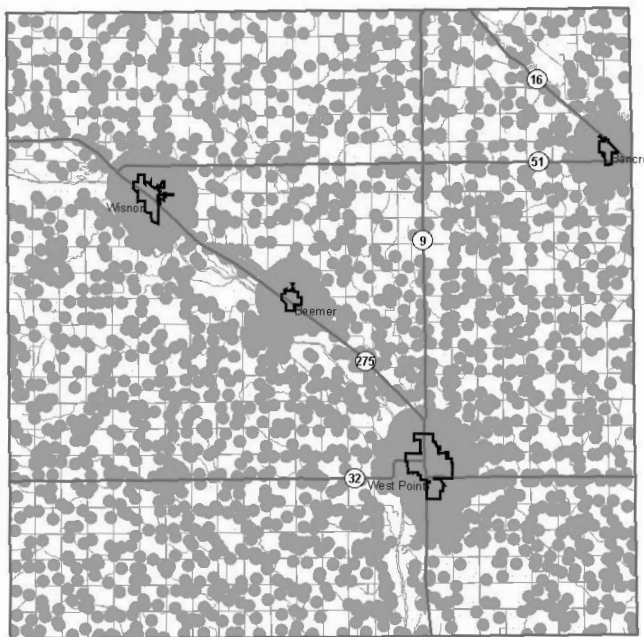


Figure 2. Land area available in Cuming County (shown in white) for expansion of livestock operations with between 301-1,000 animal units (1/4 - mile setback).

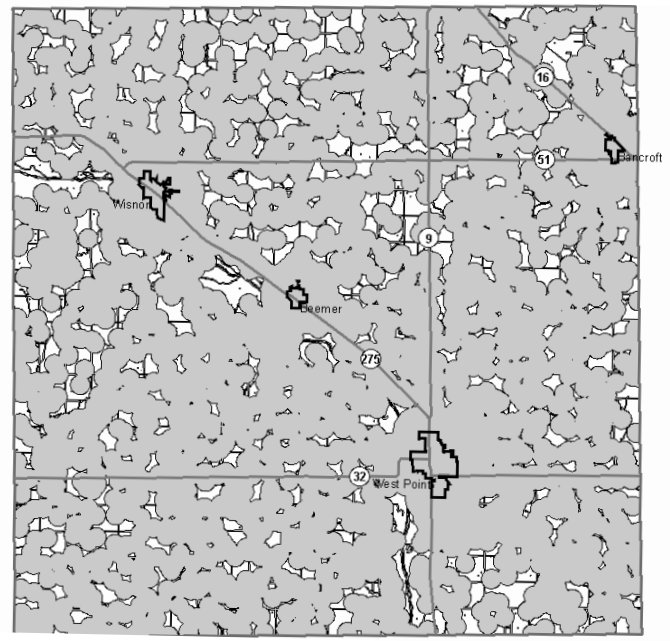


Figure 3. Land area available in Cuming County (shown in white) for expansion of livestock operations with between 1,001-5,000 animal units (3/8 - mile setback).

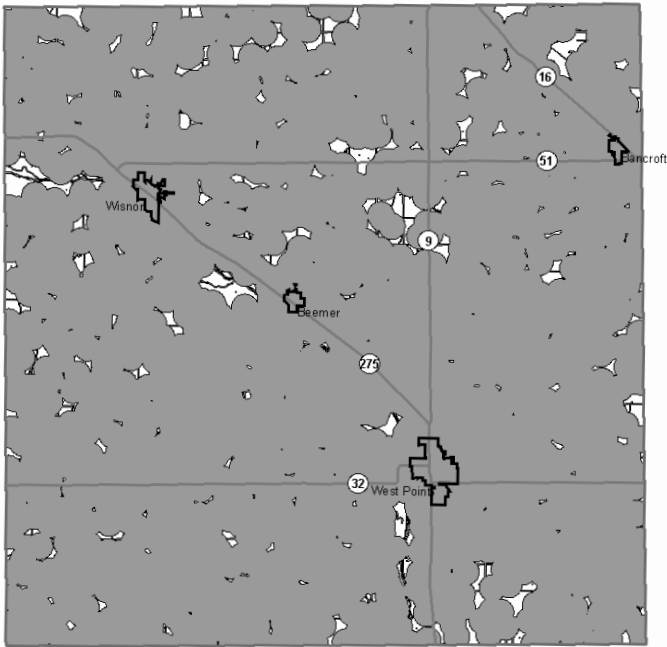


Figure 4. Land area available in Cuming County (shown in white) for expansion of livestock operations with between 5,001-10,000 animal units (1/2 - mile setback).

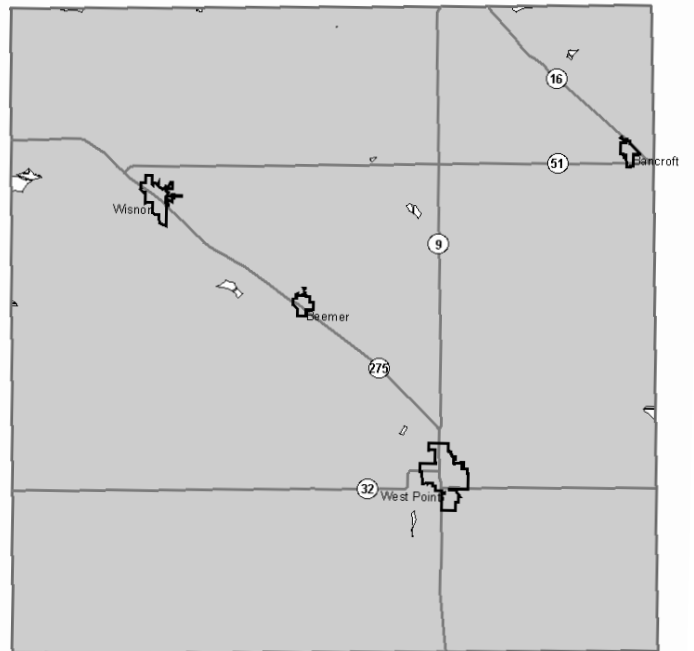


Figure 5. Land area available in Cuming County (shown in white) for expansion of livestock operations with between 10,001 - 25,000 animal units (3/4 - mile setback).

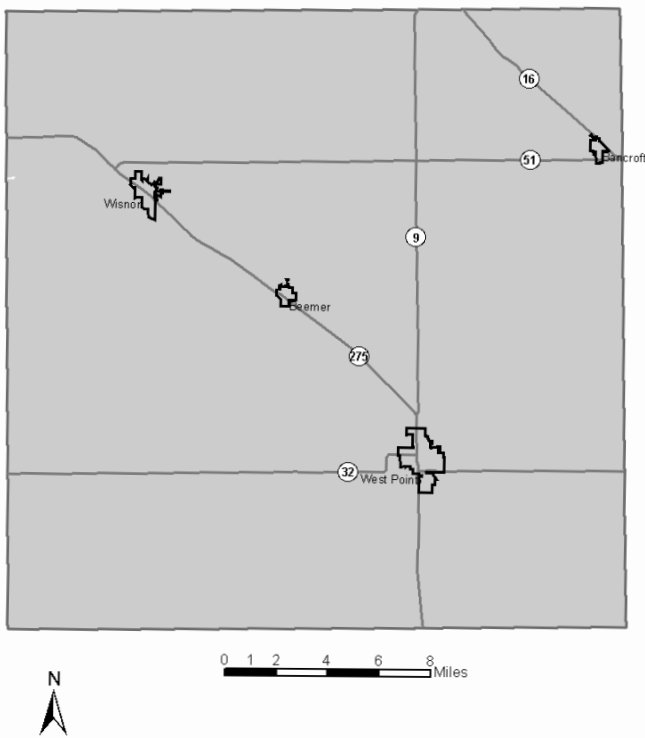


Figure 6. Land area available in Cuming County (shown in white) for expansion of livestock operations with greater than 25,000 animal units (1 - mile setback).

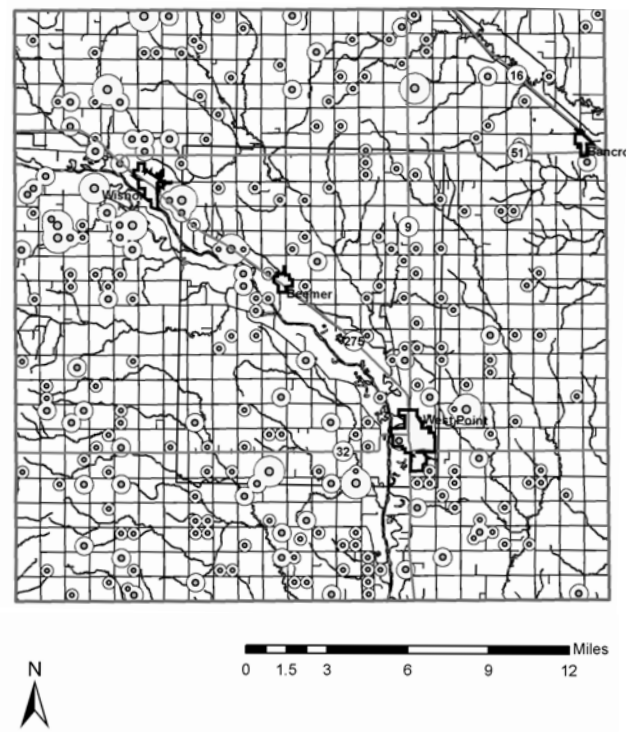


Figure 7. Land area available in Cuming County (shown in white) for rural residential development.



Table 4. Land areas excluded from livestock facility expansion or construction for given setback distances.

Setback distance from residences, mile	Acres excluded	Square miles excluded	Percent of county excluded
1/4	224,264	350	61
3/8	313,495	490	85
1/2	353,697	553	96
3/4	367,643	557	99.8
1	367,694	575	99.99

Table 5. Resulting land area excluded and available for residential development in rural areas based on a reciprocal setbacks.

All set backs from animal feeding operations	Land area excluded from new home construction (acres)	Land area excluded from new home construction (sq miles)	Percent of county new home construction	Percent of county available for new home construction
All current livestock facilities	74,810	117	20	80

leaves only 15% of the county available. An additional constraint for a potential livestock entrepreneur would be to find a location large enough for a new livestock operation at the larger class sizes. That constraint is not shown in Table 4, but it can be observed in Figures 2-6.

The expansion of existing livestock facilities would be restrained

by the required setbacks. This analysis assumes that the land available is not being used for another purpose, such as other agricultural uses, so the actual land available would be expected to be less than reported in Table 4.

In general terms, it is likely that operations with less than 5,000 AU's could locate in Cuming County, but larger operations would essentially

be excluded by the sliding scale setbacks. Facilities with less than 1,001 AU should be able to locate without much difficulty in satisfying setback requirements. It is not clear how many existing operations would be excluded from expanding, but they would have to be located in the white areas shown in Figures 2-6. The colored areas in Figures 2-6 show the land area that livestock facilities could not be located. Areas in white would be available to build or expand livestock facilities.

The results of implementing setbacks from livestock facilities reciprocally to new residential construction are shown in Figure 7 and Table 5. Even with these setbacks, over 80% of the county is still open to new housing construction, primarily in the rural areas of the county.

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Nebraska Supreme Court Rules City Can Regulate Animal Feeding Operation

J. David Aiken¹

municipal regulations may be vulnerable to future legal attacks.

Summary and Implications

Nebraska statutes authorize second class cities and villages to adopt regulations protecting municipal water supplies from pollution within 15 miles of their community borders. Livestock facility regulations implemented by the second class city of Alma that were stricter than those of the Nebraska Department of Environmental Quality were upheld by the Nebraska Supreme Court. However, similar

The construction of large swine facilities has been very controversial in Nebraska for the past several years. A major focus of the "hog wars" has been county livestock zoning regulations. In Nebraska livestock facilities are subject to state environmental regulation by the Nebraska Department of Environmental Quality (NDEQ) and also to local zoning regulations if the county is zoned (or if the livestock facility will be

located near a zoned community). The number of zoned counties has more than doubled in the last decade, from 36 to at least 80. Most of the newly zoned counties have adopted zoning in order to regulate the size and location of confined livestock facilities. The legal ability of counties to regulate livestock facilities through zoning regulations was confirmed by the Nebraska Supreme Court in 2002, when the court ruled that a Holt County zoning regulation could require a conditional use zoning

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permit before swine production facilities could be developed. *Premium Farms v Holt County*, 263 Neb 415 (2002).

Concern regarding the negative effect of some county zoning regulations on livestock expansion has led to the formation of the "Nebraska Agriculture Industry Partnership," a wide-ranging coalition of livestock industry supporters endorsed by Gov. Mike Johanns and Rep. Tom Osborne (see the NAIP website at <http://nebraskalivestock.com>).

While most of the hog-war battles have involved county zoning, at least one community has joined the fray. In 1997, the community of Alma (pop. 1,214) learned that Furnas County Farms (FCF) and Sand Livestock Systems planned to build a large swine confinement approximately eight miles northwest of the Alma city limits in Harlan County. The proposed finishing facility would have a one-time capacity of 30,000-36,000 hogs. The city hired an environmental engineer to prepare a report on the potential impact of the swine facility upon Alma's water supply. On the basis of the consultant's report Alma adopted five municipal ordinances, based on Nebraska Revised Statutes §§17-536 and 17-537. Section 17-536 establishes that the authority of cities of the second class (population of 801-5000) and villages (up to 800 population) "to prevent any pollution or injury to the stream or source of water for the supply of such [community] waterworks, shall extend fifteen miles beyond its corporate limits." The Alma ordinances required livestock producers to obtain permits from the city before developing livestock facilities within 15 miles of the city limits. The permit process required the applicant among other things to line waste lagoons with a synthetic liner, to install monitoring wells for ground water pol-

lution detection, and to submit a financial bond for cleanup.

Alma notified FCF of the permit requirements. FCF informed the city that FCF believed the city ordinances to be legally invalid, and stated its intention to proceed with construction activities. The city filed suit, and FCF stopped facility construction.

FCF contended in court that the 15 mile municipal water pollution control authority was preempted by the Nebraska Environmental Protection Act (NEPA), and because FCF had received its state permits from the NDEQ, FCF therefore was legally entitled to construct its livestock facilities without regard to the Alma ordinances. The district judge ruled in favor of Alma. An appeal to the Nebraska Supreme Court resulted in the matter being returned to the district court in 2001 for further proceedings. The district judge again ruled for Alma, and this decision again was appealed.

The Nebraska Supreme Court ruled that the 15 mile municipal water pollution control authority was not preempted by NEPA. Normally, the courts will attempt to validate both state law and local ordinances if they are clearly inconsistent. In its NEPA analysis, the court noted several NEPA provisions encouraging municipalities to establish their own local pollution control programs. The court did, however, invalidate the Alma cleanup bond requirement as being inconsistent with NEPA. The court also ruled that FCF could not raise the issue of whether the Alma ordinances conflicted with the NDEQ title 130 livestock waste control facility regulations and the Livestock Waste Management Act (LWMA) because such issues had not been raised in the district court. The *Alma* decision is another judicial warning to livestock facility developers that they ignore local regulations at their peril.

Commentary

The outcome of the *Alma* case may have been different if FCF had been able to argue that the title 130 regulations and the LWMA preempted the Alma water quality regulations. If the Alma lagoon lining requirements and monitoring well requirements were different than those established by NDEQ in approving FCF's construction permit, FCF would have had a strong argument that the Alma ordinances were preempted by NDEQ's title 130 permit requirements. Further, neither title 130 nor the LWMA have provisions paralleling the NEPA provisions encouraging the development of local pollution control programs (although §52-2404.01 acknowledges county zoning). These differences could persuade a court to reach a different conclusion from the *Alma* court. These issues are likely to be raised if municipal regulation of livestock facilities are challenged in court again.

Municipal and county livestock regulations will continue to generate controversy. Most zoned counties establish setbacks for livestock operations, and some counties have larger setbacks (up to 2 miles) for very large facilities. These types of zoning regulations make livestock expansion difficult in much of Nebraska. Hopefully, future livestock production techniques will be improved such that the nuisance aspects of livestock production (odors, flies, etc.) are significantly reduced. Until such improved production practices materialize, however, few Nebraska cities and counties significantly restricting livestock facility development are likely to relax those restrictions.

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Livestock Friendly Counties Statute Enacted

J. David Aiken¹

Summary and Implications

LB754, adopted in 2003, (1) allows the Nebraska Department of Agriculture to designate counties as livestock friendly and (2) changes procedures for county livestock zoning permits. Counties must upon request specify what an applicant must do in order to obtain a livestock zoning permit. Counties must provide written statements regarding why a livestock zoning permit is granted or denied. Applicants can upon request be informed of whether they will receive a county zoning permit before applying to the Nebraska Department of Environmental Control for a livestock waste control facility permit. LB754 is the latest (but not the final) chapter in an ongoing legal and political battle over livestock production.

Nebraska has always been a major livestock-producing state. Traditionally, most livestock production was on small to medium sized family operations. Nebraska has always had some large cattle feedlots, but most feedlots have been smaller. Swine production traditionally has been on small and medium sized operations. Just over one-third of Nebraska counties were zoned by the late 1970s, with quarter-mile (or smaller) setbacks being a common livestock zoning regulation.

Beginning in the late 1960s, large confined swine production facilities were developed in the eastern US, similar to the poultry industry. These large swine confinements did not begin to reach Nebraska until the mid- to late 1980s. Initiative 300's corporate farming restrictions no doubt slowed the development of large swine confinements in Nebraska until the early to mid-1990s. This development then became a

high-profile public policy issue. Strident opposition to large swine confinements from smaller swine producers and neighbors concerned about odors and pollution led to a temporary delay in processing livestock waste permit applications until regulations could be changed to deal with larger operations. Many features of the new state livestock waste control regulations were included in the 1998 Nebraska Livestock Waste Management Act.

Livestock zoning became a political battleground. Many unzoned counties sought to develop zoning to give them control over the location (and size) of large swine confinements. Anti-confinement groups sought changes in county zoning laws to allow temporary zoning so that counties had time to develop permanent zoning. Temporary zoning legislation was first proposed in 1998 but was not adopted until 1999, as confinement developers lobbied hard in 1998 to have the law delayed. This allowed some confinements to be developed before counties could regulate them through temporary zoning. Now most Nebraska counties are zoned; some regulations are strict enough to make development of new confinements difficult.

In most zoned counties, new livestock facilities need both (1) a state livestock waste control permit from the Nebraska Department of Environmental Quality (DEQ) and (2) a county zoning permit. Often counties will require the producer to first obtain the DEQ permit before the county will issue the zoning permit. Some livestock producers have received their DEQ permit, only to then have their county zoning permit request denied. A livestock producer may spend hundreds or thousands of dollars on application fees and consultants to obtain the DEQ permit.

Most producers would prefer to know whether or not the county will issue the zoning permit before spending the money to obtain the DEQ permit.

Legislative Bill 754, adopted in 2003, has two main provisions: (1) establishing the livestock friendly county designation program within the Nebraska Department of Agriculture, and (2) changing the county livestock zoning permit process.

Livestock Friendly Counties

The LB754 livestock friendly county program is based on the 2002 Minnesota livestock friendly county program administered by the Minnesota Department of Agriculture (MDA). The MDA livestock friendly county designation process requires among other things that counties (1) do not exceed the livestock facility setback distances in the table below and (2) do not establish "animal unit caps" or ceilings on livestock operation size.

Minnesota Recommended Maximum Separation Distances for Livestock Friendly County Designation

	separation distances
neighboring residence	1000 feet
park	2640 feet (0.5 mile)
church	2640 feet (0.5 mile)
10 or more residential dwellings	5280 feet (1 mile)
residential district or development	2640 feet (0.5 mile)
municipal boundaries	2640 feet (0.5 mile)

Sources: Minn Dept of Agriculture, "The Livestock-Friendly County Designation Process," page 2 (available at www.mda.state.mn.us/agdev/lfcapplication.pdf); Minn Dept of Agriculture, "Summary of Animal-Related Ordinances in Minnesota Counties," available at www.mda.state.mn.us/agdev/animalord.html.

The Minnesota recommended livestock-friendly setbacks would be exceeded by many zoned counties in Nebraska.

(Continued on next page)



LB754 first declares that “the growth and vitality of the state’s livestock sector are critical to the continued prosperity of the state and its citizens.” LB754 then authorizes the Nebraska Department of Agriculture (NDA) to establish criteria to recognize and assist county efforts to maintain or expand their livestock sector. Counties may be designated as livestock friendly if they request the NDA designation and meet the NDA livestock-friendly criteria. Counties may also designate themselves as being livestock friendly. The implicit objective of the NDA livestock friendly designation process is to allow counties to signal to producers whether or not they are receptive to new and/or expanded livestock operations. It will be interesting to what criteria the Nebraska Department of Agriculture will use to identify livestock-friendly counties, and whether many zoned counties will seek livestock-friendly designation. Livestock friendly designation may be significant in that at least one dairy recruited to Nebraska by state agriculture and economic development officials ended up losing a protracted

legal battle for a county zoning permit—a permit that the county wanted to grant! The livestock friendly designation process may help avoid such economic development misfires in the future.

County Livestock Zoning Permits

LB754 amends county zoning statutes to authorize a livestock producer applying for a livestock zoning permit to request the county to indicate what specific requirements the producer must meet in order to receive zoning permit approval. If such conditions are identified, and the producer receives the DEQ environmental permit, final zoning permit approval may be withheld by the county only (1) if there is a substantial change in the proposed use or (2) if the zoning conditions established by the county will not be met by the applicant. In addition, LB754 requires a written statement of the reasons why a the livestock zoning permit was granted or denied. The implicit objective of the LB754 zoning requirements is to allow applicants to get an advance written determination of whether or not their

permit will be granted before they seek the more expensive DEQ permit. At least a few Nebraska counties already follow this general procedure. Some counties may need to modify their livestock zoning permit process to comply with the new LB754 county zoning requirements.

In 2002 livestock and some agricultural interests sought a state study of the economic importance of the Nebraska livestock industry. That proposal was defeated by anti-confinement interests and others who saw it as laying the foundation for a political attack on county zoning. LB754 is what livestock advocates were able to obtain legislatively in 2003. It will be interesting to see how many zoned counties apply for NDA livestock friendly designation, especially since so many of them worked so hard to obtain livestock zoning authority to restrict livestock development.

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Property Valuation May Be Reduced by Proximity to Livestock Operation

J. David Aiken¹

Summary and Implications

Livestock odors must be taken into account when counties determine the fair market value of rural residences for property tax purposes. Livestock odors may reduce property values and property valuation. Such reductions may lead to legal nuisance liability claims against livestock producers who are not protected by the Nebraska Right

to Farm Act, and may also become a factor in livestock facility zoning decisions.

In Nebraska, land and buildings are valued at their fair market value for purposes of property taxation. Residential and commercial real estate is valued at 92-100% of actual value (i.e. fair market value) and agricultural real estate is valued at 74-80% of actual value. Fair market value for property tax valuation purposes may be determined by (1) comparative sales, (2)

income or (3) cost. In *Livingston v Jefferson County Board of Equalization*, 10 Neb App 934 (2002), the Nebraska Court of Appeals ruled that the county board of equalization erred in not considering a rural residence’s proximity to a swine farrowing facility in determining the residence’s fair market value.

The taxpayer started a swine farrowing operation in 1990. In 1999 the taxpayer built a house approximately 3/4 of a mile from his farrowing facility at a cost of \$328,649.



In 2000 the county valued the house (excluding the land) at \$399,321. The taxpayer objected to this valuation for three reasons. First, the house was approximately 3/4 of a mile from a swine farrowing facility with 5,200 sows. Second, the taxpayer had obtained an easement to apply hog manure to cropland across the road from the house. Third, the house was not served by a public road but only by a private road that at times could be used only by a four-wheel drive vehicle. The taxpayer's appraiser discounted the value of the house (based on comparable sales) by 30% for livestock odors and another 10% for its remote location.

In Nebraska, the county board hears property valuation protests, sitting as the county board of equalization. The Jefferson County board of equalization refused to modify its valuation of the Livingston property, and the county's determination was upheld on appeal by the state Tax Equalization and Review Commission (TERC). Both the county and TERC refused to consider the effects of livestock odors and the residence's remote location as being factors that would affect the property's market value.

Normally courts will presume that county officials have properly valued property for property tax purposes, and a county board of equalization need not present evidence to justify its valuation. In this case, however, the Nebraska Court of Appeals concluded that the taxpayer had successfully overcome this legal presumption that the county's valuation was correct. The court determined that it was reversible error for the county and TERC to refuse to consider the effects of the swine facility, the manure easement, and the house's remote location on its property value. The fact that the swine facility was owned by the taxpayer did not mean that the nearness of the swine facility could not be a factor in determining the residence's market value.

The court also ruled that the county board of equalization and TERC erred in refusing to consider whether the taxpayer had "overbuilt," i.e. spent more on his residence than he could realistically expect to receive if the house were sold. The taxpayer testified that he would be lucky to receive \$200,000 for the house (which probably was reasonable, given its remote location and the swine odors). The court quoted an example where a house costing \$150,000 and built in a neighborhood where the average house was worth \$75,000, would likely have a property value of less than its \$150,000 cost because the house was "overbuilt" (or too expensive) for the neighborhood.

The county failed to produce any evidence (1) that the taxpayer's house was not overbuilt and (2) that the swine odors would not affect the property value. The court of appeals ruled that (1) failure to consider whether the house was overbuilt and (2) failure to consider the impact of hog odors on property value both were reversible error. The court noted that these factors certainly would come into play when the house was sold, and would certainly influence the price paid after negotiations between a willing buyer and a willing seller. The court quoted Nebraska livestock nuisance decisions as proof that the presence of hog odors could affect what a willing buyer would be willing to pay for the house. The court ordered the county to consider the impacts of hog odors and remote location in valuing the taxpayer's property.

The court concluded that "It was arbitrary for the [county] Board and TERC to ignore the effect that the nearby hog facility would have on the house's fair market value in the ordinary course of trade. No reasonable fact finder could conclude that in the real estate marketplace, a potential buyer would not notice, and react economically, to having a large hog facility very

nearby while living in a remote location."

Commentary

The Court of Appeal's characterizations of the Livingston farrowing facility as being a "large hog facility" and the 3/4 mile distance between the farrowing facility and the Livingston residence as being "very near" are revealing and worth pondering by livestock producers and county zoning officials. Several zoned counties with livestock facility setbacks would not require a 3/4 mile setback for a confinement of just over 2000 animal units. Yet the court's comments in *Livingston* suggest that the 3/4-mile distance in that case was inadequate, contributing to a significant property value reduction.

It will be interesting to see whether this decision encourages rural residents living near livestock facilities to seek property valuation reductions due to the impact of livestock odors on the value of their residence. It also will be interesting to see if neighbors who receive such valuation reductions will then sue the livestock producer to recover the lost property value. If the livestock operation had been developed before the neighbor's residence, the livestock operator would not be liable for any lost property value under the Nebraska Right to Farm Act. However, if the residence predated the livestock operation or a livestock facility expansion, the livestock producer would not be legally protected. The potential effect of new or expanded livestock facilities on the valuation of neighboring properties may become a more important factor to those county boards making controversial livestock facility zoning decisions.

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Team Approach to Management

Allen Prosch¹

Summary and Implications

Managerial ability has been described as consisting of supervision and coordination. The coordination aspect is that function of deciding what business arrangements should be entered into. Pork producers are being called on to justify their right to do business with records that assure society that they have complied with regulations and used best management practices. Coordinating all the business activities to ensure compliance challenges the ability of any manager. The greater need for coordinating ability strongly suggests that pork producers who develop greater coordinating capacity will have a competitive advantage. Team management will be a necessary component in creating that advantage.

Introduction

In 2003, researchers found that pork operations using production contracts had improved productivity. The researchers asserted that improvement in the quality of managerial inputs such as improving information transfers and facilitating access to credit may account for such improvements. Others have suggested that fixed managerial ability causes agricultural operations to suffer diseconomies of size due to the inability to coordinate the more complex business. Furthermore, it has been argued that managerial ability consists of both supervision and coordination. Supervision is crucial for numerous individuals to work together to complete responsibilities for common production results. Coordination is the critical function of deciding which arrangements or contracts should be entered into by the business. While one can hire additional

supervisors, it is difficult to hire more people who actually decide what arrangements or contracts the operation will use. Owners do not readily give up that responsibility. Having one decision maker becomes a limiting factor for the performance of the operation. The solution to this fixed unit is the productive combination of management that assigns responsibility for parts of the decision process. The need is reduced for one decision maker to have all available knowledge that can affect the business.

Pork Production System Performance

Today's systems-oriented pork producing operations require a high level of supervision and coordination. Systems can quickly become ineffective if everyone involved in the operation is not supervised so they work together. Strategies to boost efficiency are usually complex and require a great deal of cooperation among individuals. Detailed records are needed to improve supervision and allow monitoring the system. Everything in the production system, from daily production records, facilities con-

dition record, environmental system records, feed use records, antibiotic withdrawal records to delivering the final product must be analyzed in order for the system to be competitive. Analysis must be accompanied with a method of supervisory intervention whenever the system is not performing well.

Information Flow

All of this information must originate with the employees and the supervisors. This information needs to flow seamlessly between the production personnel and supervising personnel. Bringing these people together for special or regular meetings is important for the system to perform at its best. Moving the information from the production stage to the decision makers requires another seamless transition.

Many operations rely on advice from consultants to ensure long-term profitability. Including them in the information flow takes even more effort. As information moves from person to person it becomes increasingly distorted and less accurate (Figure 1). Cooperation, understanding and trust between

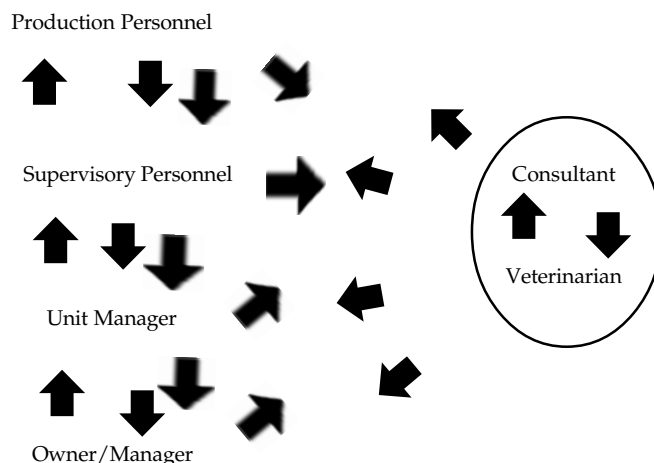


Figure 1. Accurate (sharp arrows) and distorted (fuzzy arrows) information flows. Information must flow to all simultaneously and seamlessly.



consultants, managers and employees are essential. Regular meetings with open communication are needed to ensure the team is productive.

Beyond the traditional production system, 21st Century agriculture is called on to justify its right to be in business with business records that go beyond production or profit and loss. The business now also needs to assure society that it has complied with regulations and used best management practices. Records are needed to document performance. Even further, information needs to be available for a variety of non-regulatory market issues. Customer preferences include issues like safe working conditions, animal care and history and systems that do not pollute the environment. These issues drive processors to request data on the way livestock and crop products are handled and raised. While initially thought of as a way of niche marketing a differentiated product, identification and information on commodity products is fast becoming part of information expected for mainstream products. For pork producers, programs like Pork Quality Assurance (PQA), Trucker Quality Assurance (TQA) and the Swine Welfare Assurance Program (SWAP) are becoming standards for producers to engage in and document. Future consumer demands or regulations like Country of Origin Labeling (COOL), environmental site management, and the Environmental Protection Agency (EPA) Confined Animal Feeding Operation (CAFO) regulations will challenge producer coordination.

Team Approach

All managers are challenged by the coordination of a multitude of business activities. Referring to essentially a dynamic function, decisions regarding business methods, arrangements, markets, contracts and partners become critical to success.

During times of relative stability when there are few significant changes in production, distribution, or marketing in a given industry, the effect of one person performing the coordinating task is reduced. If all agreements are in place and nothing goes wrong, the operation performs more on the supervisory level. But the most dramatic changes occurring in agriculture are best described as changes in the fundamental business proposition and the ways producers do business, according to a Purdue University professor. That professor described six critical dimensions of doing business:

1. Processes and activities that create the products or services.
2. Product flow (transportation, logistics, scheduling, inventory management, etc.)
3. Financial (cash) flow among participants
4. Information flow among all participants
5. Incentive systems to reward and share risk among all participants
6. Governance/ coordination systems (i.e., joint ventures, open access markets, strategic alliances, etc).

Traditionally producers have been able to participate well in the first two of these six dimensions. It is becoming increasingly critical to understand and participate in all six dimensions. The management ability to do so is critical.

Rapid change continues to take place within the pork industry. Much change has been internal as new technologies were adopted. More change follows with the impact of new technology altering long-time relationships between participants in the pork industry. Continued change will occur as those things that affect our businesses from the outside become more pronounced. Issues like environmental regulation, meat quality, product liability

and animal welfare may create rapid change and have greater impact than that we have experienced. The greater need for the coordinating ability of management during periods of change such as this strongly suggests that pork producers who develop greater coordinating capacity will have a competitive advantage. Team management will be an important component of the solution.

Producers with fewer human resources will need to create ways to reduce the limits imposed by an individual decision maker. Processes that consolidate information and assist analysis can help decision makers. To those who can create such processes there is opportunity. Contract production is an example of such a process and opportunity.

Other alternatives are also possible. Producers may work together to accomplish tasks similar to having a larger management team. Pork producers could form a working group that allows each owner operator the latitude to completely manage a stage of the production and marketing system. Included would be an incentive systems to reward and share risk among the participants. An overall coordinator might be hired as an outside observer. Such a system would require producers working together with greater reliance on one another than is usual among independent decision makers. Willingness to be participants in a working group, sharing common goals and utilizing common support may determine some producer's ability to compete. Pork producers need a trusted team of management support. Developing such a team is just one of the new challenges faced by pork producers.

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Crop Residue Cover and Manure Incorporation — Part I: Reduction of Cover

David P. Shelton¹

Summary and Implications

Manure incorporation represents a compromise between best management practices for soil erosion control and manure management. Manure should be incorporated into the soil for odor control, increased availability of nutrients and control of potential manure runoff. However, soil and crop residue disturbance should be minimized for soil erosion control. This field study was conducted to: 1) determine the influence that commercially available soil-engaging components used to simultaneously apply and incorporate manure have on the reduction of crop residue cover [Part I - this article]; and 2) determine and evaluate some of the factors that may influence the amount of residue cover reduction that occurs with these components [Part II - companion article]. Seven different configurations of manure injectors/applicators were operated in residue from irrigated and non-irrigated corn, soybeans and oats in the fall and/or spring of three different crop years.

Averaged across crop, year and season, residue cover reduction was significantly less for coultter-type applicators than for disk-type applicators ($P < 0.001$), disk-type applicators reduced residue cover significantly less than chisel and sweep injectors ($P < 0.001$), and chisel and sweep injectors reduced residue cover similar to a tandem disk ($P = 0.398$). Ranges of values to estimate the percentage of the initial amount of corn (non-fragile) residue cover that will remain following the use of manure application/incorporation components are: chisel and sweep injectors, 30 to 65 percent; disk-type applicators, 40 to 65 percent; and coultter-type applicators, 80 to 95 percent. Similarly, for soybean or oat (fragile) residue, estimates of the initial residue cover remaining are: chisel and sweep injectors, 5 to 15 percent; disk-type applicators, 15 to 40 percent; and coultter-type applicators, 65 to 80 percent. These values can be used for estimation or planning purposes when site-specific data are not available. Results of this research indicate that certain configurations of manure application/incorporation equipment may leave adequate residue

cover for acceptable soil erosion control, particularly in non-fragile residue. However, the equipment must be selected, adjusted and operated with the dual objectives of residue and manure management, rather than used simply as a means of manure disposal.

Background and Introduction

Effective management of manure has become an increased focus of many swine producers due to environmental concerns such as water quality and odor control, and to better capitalize on the fertilizer value of the manure. A best management practice (BMP) is to incorporate manure into the soil to maximize nutrient availability, especially nitrogen, and to minimize odors and potential degradation of surface water quality through manure runoff.

Maintaining crop residue on the soil surface is one of the most cost-effective soil erosion control practices. Erosion can be reduced by 50 percent of that occurring from a cleanly tilled field when just 20 percent of the soil surface is cov-

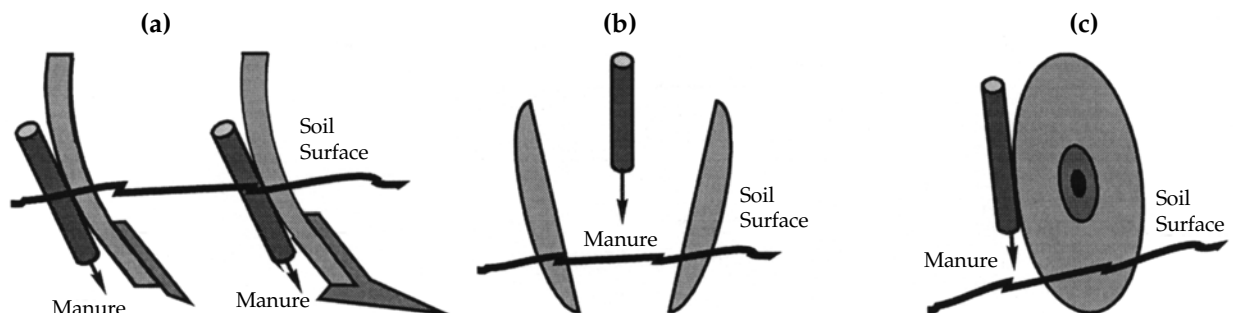


Figure 1. Schematic of typical soil-engaging components used for simultaneous application and incorporation of manure: (a) chisel and sweep injectors; (b) disk-type applicator; and (c) coultter-type applicator.



Table 1. Summary of injection/application equipment used.^a

Chisel and sweep injectors

Balzer 20.5 in. wide sweeps with integral 2.25 in. wide straight chisel points; 30 in. spacing on toolbar
Balzer 20.5 in. wide sweeps with integral 2.25 in. wide straight chisel points and 17.5 in. diameter ripple coulters in front of each injector; 30 in. spacing on toolbar
Calumet 2 in. wide straight chisel points; 30 in. spacing on toolbar
Calumet 14 in. wide sweeps; 30 in. spacing on toolbar

Disk-type applicators

Calumet Disk Applicators; 16 in. diameter disks spaced 16 in. at their centers; 30 in. spacing on toolbar
Vittetoe Disk Applicators; 22 in. diameter disks spaced 31 in. at their centers; 60 in. spacing on toolbar

Coulter-type applicator

Sukup Manufacturing 25 in. diameter coulters applicators; 30 in. spacing on toolbar

Knife-type anhydrous ammonia applicator

Blue Jet 0.5 in. wide rigid C-shaped knife shanks with 20 in. diameter smooth coulters in front of knives; 30 in. spacing on toolbar

Tandem disk

John Deere model TO210; spring tooth harrow attachment

^aMention of brand names is for descriptive purposes only. Endorsement or exclusion of others is not intended or implied.

ered with residue. A soil erosion control BMP is to minimize soil and crop residue disturbance, thus leaving greater amounts of crop residue on the soil surface.

These two BMPs are in conflict since disturbance of the soil and residue for manure incorporation, either with conventional tillage implements or with equipment specifically designed for manure application/incorporation, will reduce the amount of residue cover remaining on the soil surface for erosion control.

Although estimates of residue cover reduction by tillage and other soil-engaging implements are available in tabulated form and computer programs, estimates of residue cover reduction by manure application/incorporation equipment are not well documented. Therefore, a research project was conducted to: 1) determine the influence that commercially available soil-engaging components used to simultaneously apply and incorporate manure have on the reduction of crop residue cover [Part I - this article]; and 2) determine and evaluate some of the factors that may influence the amount of residue cover reduction that occurs with these components [Part II - companion article].

Procedures

Soil-Engaging Components

Three general configurations of soil-engaging components are typically used with tank spreaders and towed hose systems to simultaneously apply and incorporate either liquid or slurry manure. These are:

Chisels and sweeps (Figure 1a) are the most common components for manure application/incorporation. These generally consist of a C-shaped shank, 2-3 inches wide, with either a chisel or sweep point bolted to it. Shank spacing on the toolbar usually ranges from 20 to 60 inches. Chisel points are typically 2-3 inches wide, and can be either straight or twisted. Sweeps are typically 7-24 inches wide. At least one manufacturer offers a combination chisel point and sweep as a single unit. Most manufacturers also offer coulters that can be mounted in front of the shanks to help cut the crop residue, which improves residue flow between and around the shanks. Operating depth of chisels and sweeps is usually 4-8 inches. Manure exits the supply tube below the soil surface, making these units true manure injectors.

Disk-type applicators (Figure 1b) consist of two opposed concave disks, typically 14-22 inches in diameter, mounted on an angled shaft. Spacing between the centers of the individual disks is generally 12-32 inches. Because of the angled shaft, the disks are skewed relative to the direction of travel, giving a wider spacing between the disks at the front edges than at the rear. Manure exits slightly above the soil surface through the supply tube between the disks. Operating depth of the disks is generally 3-6 inches. As the applicator moves through the field, the disks throw loosened soil and crop residue inward and upward, mixing the soil and residue with the manure flowing from the supply tubes. Following application, the field often appears as strips of essentially undisturbed residue and soil alternated with strips of mixed soil, residue, and manure. The width of the undisturbed strip is dependent on both the spacing between the two opposing disks, and the spacing of the disk units along the toolbar, which is typically 15-60 inches.

Coulter-type applicators (Figure 1c) consist of a large rolling coulters, typically 22-25 inches in diameter, a manure supply tube, and a closing or press wheel. The coulters is angled approximately 5 degrees compared to both the direction of travel and to vertical. As the applicator moves through the field, the soil and residue is cut by the coulters and a slot is wedged open. Manure is applied in this slot, and the press wheel then forces the slot closed. Operating depth of the coulters is usually 4-8 inches. Coulter applicators are typically operated in pairs, with one skewed to the right and one skewed to the left, to eliminate implement side-draft.

Seven configurations of commercially available manure injection/application components were evaluated in this research (Table 1). A tandem disk and a knife-type anhydrous ammonia applicator

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were also included for comparison purposes. Evaluations were made in both irrigated and dryland corn residue (non-fragile residue) and in soybean and oat residue (fragile residue). Trials were conducted at the University of Nebraska Haskell Agricultural Laboratory near Concord in the spring and fall of 1996 and 1997. Partial funding was provided by the Nebraska Pork Producers Association.

Results and Discussion

Residue Cover Reduction by the Components

Residue cover reductions as great as 98 percent occurred in soybean and oat residues for some of the chisel and sweep injector treatments. In all cases, when chisel and sweep injectors were used in either soybean or oat residue, cover reductions of 70 percent or greater occurred. Taken across year, season and specific equipment, the mean residue cover reduction was 92 percent when chisel and sweep injectors were used in soybean and oat residues. Likewise, the mean residue cover reduction was 52 percent when chisel and sweep injectors were used in corn residue, with reductions ranging from 25 to 87 percent. Mean cover reductions by chisel and sweep injectors were not significantly different ($P \geq 0.110$) from the reductions by the tandem disk in any of the four types of residue.

Mean residue cover reduction by the disk applicators taken across year and season was 72 percent for soybean and oat residues and 45 percent for corn residue. Residue cover reduction by the disk applicators was not significantly different ($P \geq 0.130$) compared with the tandem disk in either irrigated or non-irrigated corn residue, but was significantly less ($P < 0.001$) in soybean and oat residues.

Residue cover reductions by the coulter-type applicator were sig-

Table 2. Percentage of initial residue cover remaining following manure application/incorporation.

Application/Incorporation Component	Percentage of Initial Residue Cover Retained	
	Soybean and Oat Residue (Fragile)	Corn Residue (Non-fragile)
Chisel and Sweep Injectors	5-15	30-65
Disk-Type Applicators	15-40	40-65
Coulter-Type Applicators	65-80	80-95
Tandem Disk	5-25	35-60

nificantly less ($P < 0.005$) than the reductions by chisel and sweep injectors, disk applicators and the tandem disk for each of the four residue types. Taken across year and season, mean residue cover reduction for the coulter applicator was 37 percent for soybean and oat residues, and 11 percent for corn residue.

Estimating Percent Residue Cover Remaining

One objective of this research was to determine values similar to those available for many tillage and other residue-disturbing operations that could be used to estimate the amount of residue cover expected to remain for soil erosion control following operation of manure application/incorporation equipment. Suggested ranges of values for both fragile and non-fragile residues are presented in Table 2. These data can be used for planning purposes if site and equipment-specific values are not available. [Note: the values in Table 2 are percentage of initial residue cover remaining, not percent reduction as previously discussed; percentage cover remaining = $(100 - \text{percent reduction})$.]

The values in Table 2 can be multiplied by the percent residue cover present before manure application/incorporation to obtain an estimate of the amount of cover that will remain following manure incorporation. For example, assume that a coulter-type applicator is used to apply manure in a recently combined soybean field having an

average residue cover of 70%. Multiply 70% (after harvest cover) by 0.7 (estimated percentage of cover remaining for a coulter-type applicator used in soybean residue, expressed as a decimal) which gives about 50% residue cover following manure application. In contrast, if a chisel or sweep injector was used in the same soybean field, less than 10% cover would likely remain ($70\% \times 0.1 = 7\%$). Likewise, in an irrigated corn field having an average residue cover of 95%, the expected percent cover following manure application/incorporation would be approximately 40% ($95\% \times 0.45$) if a chisel or sweep injector is used; slightly over 50% ($95\% \times 0.55$) if a disk-type applicator is used; and about 80% ($95\% \times 0.85$) if a coulter-type applicator is used.

As with tillage operations, the amount of residue cover remaining after manure incorporation is influenced by many factors including: component design, shank spacing on the toolbar, adjustments, field speed, depth of soil disturbance, previous residue disturbance, soil and residue condition and others. Thus, the best procedure is to operate the manure incorporation equipment in a small, representative area of the field, and then measure the amount of residue cover remaining (refer to University of Nebraska Cooperation Extension NebGuide G93-1133, *Estimating Percent Residue Cover Using the Line-Transect Method.*) Also, manure incorporation is only one operation within a series or system of operations that are performed in a field between harvest of one crop



and planting of the next crop in that field. Each soil and residue-disturbing operation must be considered when evaluating the amount of residue that will remain for erosion control. (For a more complete listing of implements and residue amounts remaining, as well as more information about the influence of various factors on residue cover, refer to University of Nebraska Cooperation Extension NebGuide G93-1135, *Estimating Percent Residue Cover Using the Calculation Method*.)

Conclusions

Results of this research project indicate that adequate residue cover can remain for effective erosion control with some configurations of manure injectors and applicators, particularly in corn or other non-fragile residue. However, the equipment must be selected, adjusted and operated with the dual objectives of manure and residue management, rather than the objective of simply disposing of the manure. The companion article titled

"Crop Residue Cover and Manure Incorporation — Part II: "Fine-Tuning" the System" discusses some of these considerations. With this information, swine producers should be better able to select a manure management system that is also compatible with their soil erosion control objectives.

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Crop Residue Cover and Manure Incorporation — Part II: "Fine-Tuning" the System

David P. Shelton¹

Summary and Implications

Manure incorporation represents a compromise between best management practices for soil erosion control and manure management. Manure should be incorporated into the soil for odor control, increased availability of nutrients, and control of potential manure runoff. However, soil and crop residue disturbance should be minimized for soil erosion control. Values to estimate the amount of residue cover that will remain following the use of common manure application/incorporation components have been presented in the article titled "Crop Residue Cover and Manure Incorporation — Part I: Reduction of Cover." This article discusses some of the influence that injector/applicator spacing, tire spacing, field speed and several other factors can have on residue cover reduction. Much of this information is based on

field observations which may help swine producers in the selection and operation of manure incorporation components, especially when trying to maximize the residue cover that remains for erosion control.

Background and Introduction

Manure incorporation represents a conflict between best management practices (BMPs) for soil erosion control and manure management. Manure should be incorporated into the soil for odor control, maximum availability of nutrients, and control of potential manure runoff. But, for maximum soil erosion control, the soil and crop residue should remain undisturbed. These two BMPs must be balanced since disturbing the soil and residue for manure incorporation, either with conventional tillage implements or with equipment specifically designed for manure application/incorporation, reduces

the amount of residue cover remaining for erosion control.

The companion article titled *"Crop Residue Cover and Manure Incorporation — Part I: Reduction of Cover"* presents results from a research project conducted at the University of Nebraska Haskell Agricultural Laboratory that evaluated the residue cover reduction caused by various soil-engaging components typically used with tank spreaders and towed hose systems to simultaneously apply and incorporate either liquid or slurry manure. Ranges of values are given for the percentage of the initial residue cover that could be expected to remain following the operation of chisel and sweep manure injectors, disk-type applicators, coulters-type applicators and a tandem disk.

This article discusses some of the influence that injector/applicator spacing, tire spacing, field speed and several other factors can

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have on residue cover reduction. Much of this information is based on field observations and related experiences, and is intended to help swine producers in the selection and operation of manure application/incorporation components, especially when trying to maximize the residue cover that remains for erosion control.

“Fine-Tuning” the System for Residue Management

The type of soil-engaging component (chisel or sweep injector, disk-type applicator, coulters-type applicator, etc.) is the predominant factor affecting residue cover reduction during manure incorporation. However, adjustments, operating conditions and many other factors can influence the amount of cover reduction that occurs. Following is a discussion of some of these factors.

- **Applicator Spacing and Width.** Spacing of the injectors/applicators on the toolbar can have a major influence on residue cover reduction. Decreasing the spacing between these components generally will increase the amount of residue disturbance (i.e. less cover remains). There is, however, a minimum spacing where the soil surface area disturbed by one applicator overlaps the area impacted by the adjacent applicator, and the result is essentially full width disturbance.

To evaluate the degree of disturbance caused by individual injectors/applicators, passes in soybean residue were made with single injector or applicator units. The width of the disturbance (defined as loose soil on the surface) was measured perpendicular to the direction of travel in 50 places over a distance of 200 feet. The average disturbed width ranged from 7 inches for the coulters applicator to 57 inches for one of the disk-type applica-

Table 1. Average width of soil disturbance for single injectors or applicators.

Description of Injector or Applicator ^a	Disturbed Width (inches) ^b
Sukup Coulters Applicator (25 in. diameter blade, 5 mph)	7 a
Knife-type Fertilizer Applicator (0.5 in. wide knife with smooth coulters, 5 mph)	17 b
Calumet Chisel Injector (2 in. wide straight chisel, 5 mph)	36 c
Calumet Disk Applicator (16 in. disks, 16 in. apart, 7 mph)	36 c
Calumet Sweep Injector (14 in. wide sweep, 5 mph)	42 d
Calumet Disk Applicator (16 in. disks, 16 in. apart, 10.5 mph)	45 d
Vittetoe Disk Applicator (22 in. disks, 31 in. apart, 7 mph)	57 e

^aMention of brand names is for descriptive purposes only. Endorsement or exclusion of others is not intended or implied.

^bMeans followed by a different letter are significantly different (P<0.001).

Table 2. Average residue cover reduction for disk applicators with 22 inch diameter disks, 31 inch spacing between disks, and 60 inch spacing of applicators on tank toolbar.

Area	Residue Cover Reduction (percent) ^a	
	Soybean Residue	Corn Residue
Between individual disks	89 a	57 a
Between adjacent applicators	47 b	29 b
Overall	68	43

^aWithin residue type, means followed by a different letter are significantly different (P<0.001).

tors, Table 1. In general, as the width of the soil-engaging component increased, the width of disturbance also increased. For example, the coulters-type applicator consists of a 25 inch diameter coulters that is angled approximately 5 degrees relative to both the direction of travel and to vertical. The maximum profile width of this component perpendicular to the direction of travel is approximately 2 inches. At the soil surface, however, this width is on the order of 1 inch or less, depending on the operating depth. Also, soil-opening is with a cutting action, rather than a lifting or inverting action. Hence the disturbed width would be expected to be the least. Much of the disturbance that did occur was the result of soil that adhered to the coulters blade, and then fell or was thrown to the side as the implement moved through the field. For the other components, the width at the soil surface perpendicular to the direction of travel was approximately: 0.5 inch for the knife-type

anhydrous ammonia applicator; 2 inches for both the Calumet chisel and sweep (width of shank); 15 inches for the Calumet disk applicator; and 30 inches for the Vittetoe disk applicator. Also, with the exception of the coulters-type applicator and knife-type ammonia applicator, the soil-engaging components evaluated are designed to loosen and lift or throw the soil, and mix the manure with it. As such, a wider area of disturbance would be expected as the width of the soil-engaging component increased.

Results from the Vittetoe disk applicators (22 in. diameter disks with 31 in. spacing between disks) also illustrate the influence of applicator spacing. Because of the wide spacing between the two disks, these applicators were spaced 60 inches apart on the tank toolbar, rather than the 30-inch spacing used for all other injectors/applicators. This configuration resulted in strips of disturbed soil and residue between the disks, alternated with strips of essentially undisturbed soil and resi-



due in the area between adjacent applicators. Both strips were approximately 30 inches wide. Residue cover was measured in both areas. Average residue cover reductions are shown in Table 2.

As expected, significantly ($P < 0.001$) more reduction occurred between the individual disks than between adjacent applicator units. The reduction between adjacent applicators was due primarily to soil that was thrown by the disks and fell in the area between the applicators. If the applicators were spaced closer together on the toolbar, proportionately more of the total area would be disturbed directly by the individual disks, and the overall reduction would be greater. Conversely, for a given applicator unit spacing, if the individual disks were spaced closer together, less of the total area would be disturbed directly by the disks, and overall residue cover reduction would be less. Thus, to minimize residue cover reduction, the width of the applicator unit should be as narrow as possible and applicator spacing on the toolbar should be as wide as possible.

For both disk-type applicators used in this study, the spacing between the disks of each individual unit was approximately 50% of the applicator unit spacing on the tank toolbar. The values presented in Part I to estimate residue cover reduction by disk-type applicators are based on this spacing. However, field observations and manufacturer's sales literature indicate that disk-type applicators are sometimes mounted on the tank toolbar such that the spacing between the disks of adjacent applicator units is minimal (i.e. the disks are nearly hub-to-hub). In these cases, the overall reduction would likely be close to the values in Table 2 for the area between individual disks, or similar to the reductions that would be expected from chisel and sweep injectors.

- **Chisels vs. Sweeps.** More residue cover remained when chisel points were used as compared to sweeps. In corn residue, chisel points reduced residue cover by an average of 51 percent, whereas sweeps reduced the cover by 63 percent ($P < 0.001$). The width of disturbance was also significantly greater for sweeps than for chisels, Table 1.

- **Straight vs. Twisted Chisel Points.** Twisted chisel points will reduce residue cover more than straight chisel points. (Straight points were used in this study.)

- **Coulters.** Coulters are sometimes added to tillage implements or planters to cut the residue and improve residue flow around or through the equipment. Adding a coulters to the combination chisel/sweep injector in this study did not have an effect on the amount of residue cover that remained. A Canadian researcher, however, reported that the addition of a coulters in front of a sweep manure injector increased draft force by 27% and caused greater soil surface roughness compared with the sweep alone. Thus, it appears that adding a coulters to manure injection equipment should be considered only for specific situations, such as with exceptionally heavy or tough residue, not on a routine basis.

- **Disk-Type Applicators.** Residue and soil disturbance by the disk-type applicators varied considerably depending on soil conditions. Under relatively dry and/or non-cohesive soil conditions, virtually all disturbance was confined to the area between the two disks of each individual applicator unit, and the area between adjacent units remained essentially free of loose soil. Under other conditions, such as when the soil was relatively damp, a considerable amount of soil was thrown by the disks onto the area

between adjacent applicators, reducing the percent cover of this area. Also, damp/wet soil tended to stick and pack on the inside of the disks. This sometimes caused the disks to stop turning, resulting in a scraping or plowing action which left bare strips with large piles of residue at the ends. Scraper blades, similar to those often used to clean disk harrow blades, might help reduce this problem.

Disk-type applicators might fit well in a ridge-plant system. When operated on a flat field (no ridges), disk applicators leave a ridge about four to eight inches high that is a mixture of soil, residue, and manure. These ridges could be used as the start of a ridge-plant system. If manure application was done in the fall, the loose soil/residue/manure mixture would have time to settle and consolidate prior to planting on the ridge top the following spring. Similarly, if the applicators were centered on an existing ridge, some rebuilding of the ridge would occur, and manure would be applied in the area where the next year's crop would be planted. In either case, manure application rates should be carefully controlled to avoid potential seedling injury. However, a possible drawback is the potential to concentrate weed seeds, coming either from the manure itself or from the soil surface, directly in the crop row.

- **Coulters-Type Applicators.** Coulters-type applicators left the most residue cover of any of the manure injectors and applicators evaluated in this study. As such, they are the most compatible with no-till planting systems. At least one manufacturer markets a coulters applicator unit as a "No-Till Injector," although this is somewhat of a misnomer in that the manure exits the supply tube above the soil surface, and

(Continued on next page)



some disturbance of the soil and residue does occur.

It appears that coultter-type applicators might offer the opportunity to apply manure into a growing crop or pasture, a practice that has been used for some time in the United Kingdom. One UK researcher concluded that shallow injection of manure slurry into a growing cereal crop allowed manure application when crop nutrient requirements were at their maximum; provided a much larger window of time for manure application; and had no detrimental influence on crop yield. Further investigation of this manure management alternative is warranted.

- **Field Speed.** More cover generally will remain when equipment is operated at slower speeds. For example, operating one of the disk applicators at 7 mph resulted in an average width of soil disturbance of 36 inches, whereas the disturbance increased to 45 inches at 10.5 mph, Table 1.

Manure application rate (volume per unit area) is primarily controlled by field speed for some manure tanks, with faster speeds required to achieve lower application rates. Also, a speed about 10 mph was recommended by the factory representative for the Calumet disk applicator to achieve thorough mixing of the loosened soil, residue and manure being applied. Thus, in certain cases, the operator may have only limited ability to reduce field speed in an effort to leave more residue cover. This suggests that the ability to control flow rates from the manure tank, and hence control application rates independent of field speed, may be beneficial for lessening residue cover reduction and improving manure nutrient utilization. Some manufacturers are now offering this option.

- **Manure application rates.** There may be differences in the amount of manure that can be applied by the different types of injectors/applicators. It appears that as the degree of soil and residue disturbance increases, the amount of manure that can be applied while still achieving thorough incorporation also increases. For example, the coultter applicator opens a relatively small slot or channel in the soil which may overflow if large volumes of manure are applied, particularly if the soil has a low infiltration rate. In contrast, large volumes of manure can be applied with chisel and sweep injectors since, by design, a sizable volume of soil is loosened during their operation, and the manure is applied below the soil surface.

Manure application rates also may be controlled by component design. For example, manure supply tubes on the chisels, sweeps, and disk applicators used in this study were all 3 inches in diameter, whereas the coultter applicators were equipped with 2 inch supply tubes. This should not be a factor, however, if manure is applied at agronomic rates to meet crop nutrient needs.

- **Tire Spacing.** Particularly when operating in row-crop residue, tire spacing on the axles (both on the manure tank and tractor) should be adjusted to conform to plant row spacing, and the tires should be centered in the row middles. If this is not the case, standing residue can be knocked down by the tires and covered by the injectors/applicators. (Tire spacing that matches the row spacing is imperative if manure will be side-dressed into growing crops or applied in a ridged field.)

If tire spacing does not match row spacing, injectors/applicators mounted on the front of the tank (as opposed to the rear) may

leave somewhat greater amounts of residue cover. With this configuration, standing residue that was knocked down by the tank tires would be knocked down onto the area that had already been disturbed, rather than in front of the injectors/applicators. Situations similar to this have been observed when no-till planting into corn residue. Standing corn stalks were knocked down by the planter components, slightly increasing the amount of residue cover compared to the cover prior to the planting operation. However, judging from sales literature, only a very limited number of manure equipment manufacturers offer a front-mount option. Also, front-mounting may substantially limit the use of different types of injectors/applicators since clearance below the tank is usually quite limited.

- **Soil surface following application/incorporation.** All of the injectors/applicators to some extent left ridges and/or valleys in the field. These were most pronounced for the chisel and sweep injectors and the disk applicators. In the case of the chisel and sweep injectors, some type of subsequent tillage would likely be needed to smooth and level the surface prior to planting. This, as well as the planting operation, would further reduce the residue cover remaining for erosion control. For the disk applicators, subsequent tillage might not be necessary, provided that the plant row spacing matched the applicator spacing. Planting could be done either on top of the ridge as previously discussed, or in the essentially undisturbed area between adjacent applicator units. Planting in a field where coultter applicators had been used could be performed at nearly any location, although planting directly in the applicator track should be avoided to prevent seedling



injury from contact with the applied manure.

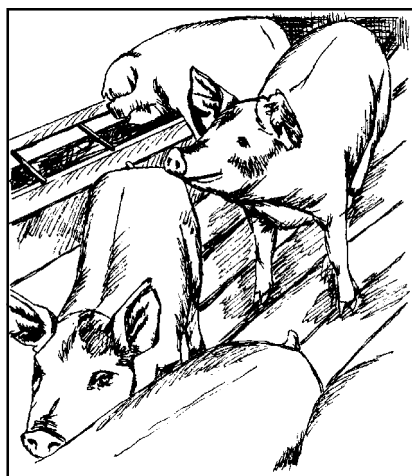
- **Apply on the contour.** Manure application/incorporation equipment should be operated on the contour, rather than up-and-down hill, to help reduce potential soil erosion and manure runoff. For example, the disk applicators tended to leave channels at both edges of the applicator track which could serve as areas for concentrated water flow. Likewise, the slot left by the coulter applicator could also serve as a water flow channel, potentially washing out the applied manure during a heavy rain. When operated on the contour, the ridges and valleys may act as mini-terraces or small dams which slow water runoff from rainfall or snow melt, thus increasing infiltration into the soil and reducing erosion potential.

- **Fall vs. Spring Application.** If manure is applied and incorporated in the fall or if the residue is disturbed in the fall by grazing, tillage, stalk chopping, or knifing-in fertilizer, subsequent spring operations reduce cover more than if all operations are conducted in the spring. These operations cut or break the residue into smaller pieces, mix soil and residue, and speed over-winter weathering, thus making the residue more susceptible to decomposition and burial in the spring. Another University of Nebraska research project showed that for the same sequence of field operations used in corn residue, residue cover measured after planting averaged 12 percent less ($P < 0.05$) when at least one operation was conducted in the fall, compared to perform-

ing all operations in the spring.

If possible, apply and incorporate manure in the spring, rather than the fall, to maximize the amount of residue cover remaining. This also more closely matches crop nutrient needs, and may reduce nutrient leaching. Also, greater amounts of residue cover would remain on the soil surface during the winter and early spring for increased erosion protection during this period. However, manure application only in the spring is not always feasible due to limitations in manure storage capacity. Also, field access and compaction may be more of a concern since the soil is usually wetter in the spring than in the fall. As mentioned previously, manure application into a growing crop or pasture may be a manure management alternative that could overcome some of these issues.

- **Oat Residue.** Oat (and possibly other small grain) residue may offer some unique opportunities for manure/residue management. With harvest typically in late summer, the window of time available for manure application is



greater than with fall-harvested crops. Also, there is often re-growth of the oat plants and/or oat seed that remains in the field due to harvest losses. For example, during one year of this study, 12 to 16 inches of new growth occurred between harvest and the first killing frost. If manure is applied/incorporated shortly after harvest, this new growth may add some residue cover to the bare areas caused by the application/incorporation operation, thus reducing the erosion potential. Additionally, vegetative growth from oat harvest losses or from a seeded cover crop may help stabilize nutrients from the manure by using plant uptake to store nutrients in the residue.

Conclusions

Results of this research project indicate that adequate residue cover can be maintained for effective erosion control with some configurations of manure injectors/applicators, particularly in corn or other non-fragile residue. However, the equipment must be selected, adjusted and operated with the dual objectives of manure and residue management, rather than the objective of simply disposing of the manure. With careful planning, swine producers should be able to select a manure management system that is also compatible with their soil erosion control objectives.

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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 effect 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% 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. But bear in mind that 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 $P < .01$. Now the chance that random sampling of




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

It is commonplace 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 that there is a tendency that real treatment differences exist when the value of P is between .05 and .10. Tendency is used because we are not as confident that 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% 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% chance that random differences between pigs on the treatments caused the observed response. 

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