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This article is the 7th in a series highlighting the unique value of soybean meal to swine nutrition and health

Profit Optimum Synthetic Lysine Level in Swine Diets Differs by Growth Phase: Growth Can be Impaired Despite Meeting the Ideal Amino Acid Profile

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Introduction

Substituting synthetic amino acids, corn and corn coproducts for soybean meal (SBM) is a reliable means of reducing diet cost. For reasons that remain unclear, relatively high levels of synthetic lysine (SL) can be fed to pigs in early phases of growth (<150 lbs.) without impairing performance compared to later phases (>150 lbs.). This persistent problem has been extensively studied in the private sector, with much of the collaboration having been with Dr. James Usry (previously with Ajinimoto North America). Growth rate (ADG) and feed conversion efficiency (FCE) become impaired when dietary synthetic lysine (SL) exceeds a certain level, despite having met the requirement for all essential (EAA) and non-essential amino acids (NEAA), dietary electrolyte balance (DEB) and other factors as described by Boyd and coworkers (2024).

This limitation to synthetic amino acid use persists, even though the commercial library of synthetic amino acids used in North American swine diets has increased from 2 to 7. During our time with the Hanor Company (2002-2020), we conducted routine dose response assays with SL to establish the maximum amount that could be used by feeding phase without impairing growth and FCE (25 to 290 lbs.). This exercise was repeated at 5-6 year intervals because the library of synthetic amino acids for commercial use was expanding. Corn distillers dried grains with solubles (DDGS) also emerged as a dietary protein source and this significantly changed the balance among protein ingredients.

A marked reduction in dietary SBM content occurred when the 4th commercial synthetic amino acid, tryptophan, became cost effective to use. The combination of the 4 amino acids and DDGS caused dietary SBM content to plummet. This dramatic shift in protein ingredient balance prompted us to conduct this study to determine whether the maximum SL level had changed from earlier internal studies (25 to 270 lbs.). We assumed that the exchange of protein ingredients would not impair growth, provided that dietary amino acid and energy value were equal. At that time, we did not consider the possible influence of functional components on growth and the advantage that legume ingredients have in their content (Petry et al., 2024).

Purpose and rationale for study

This report details the results of the SL dose response study (Zier-Rush et al., 2013a) that we conducted when synthetic tryptophan use in swine diets was becoming routine and when valine (Val) and isoleucine (Ile) were close to the price threshold needed for commercial use. Extensive use of DDGS and corn germ meal (CGM) had become routine in the Hanor system (IL region). These ingredients reduced dietary SBM content to levels that had not been seen since the 1970s.

Synthetic lysine dose curves were developed for 4 phases of growth (65 to 270 lbs.). Dose range for each phase was chosen based on results from prior internal studies to define the SL maximum. Those studies involved SL dose-response assays for a growth phase, followed by a 7-10 d period where pigs were fed a common diet before being re-allotted to test diets for the next phase. The present study involved SL dose titrations for each feeding phase without a ‘recovery’ period between phases. However, the SL dose declined as we moved from one phase to the next to minimize or prevent carryover effects.

Methods overview

This study was conducted on a 10,000 pig commercial site owned by Hanor (White Hall, Illinois). Two of the 8 barns, each housing up to 1250 pigs, were retrofitted for research and equipped with a Howeema feed blending and distribution system. A total of 2221 terminal cross pigs (Camborough sows x PIC 337 sire line) were placed in 100 pens (ca. 22 pigs/pen) with castrate male and female pigs (65.7 ± 1.0 lbs.) being placed in separate barns. Upon entry, pigs were randomly placed into pens and fed the control diet for the first 24 h. Thereafter, pigs were weighed by pen and allocated within gender and pen weight block to one of 6 dietary treatments. The control diet (low SL dose) and Diet 6 were represented by 18 pens each, whereas, the other SL dose treatments had 16 pens each.

The dose response study involved 5 SL levels and a 6th diet that was a duplicate of Diet 5 with added Ile and Val. Dietary treatments were fed to each of 4 planned growth phases: 65-105, 105-145, 145-195, and 195-270 lbs. (**Table 1**). Pen and feeder weights were recorded at about 21 d intervals. Strict protocols were in place for individual pig medication and removal to medical treatment pens for focused care. The latter were removed from the study. Medication by feed or water was not used. Mortality plus morbidity pig removals averaged 3.20%.

Table 1. Dietary synthetic lysine levels (HCl form) for each phase of growth [1, 2, 3]

Diet Phase	Start Wt. lbs/pig	Diet SID Lysine, %	SID Lysine g/Mcal NE	L-Lysine.HCl Dose, lbs./ton Diet 1	Diet 2	Diet 3	Diet 4	Diet 5	Diet 6
1	65	1.17	4.663	4.0	6.0	8.0	10.0	12.0	12.0
2	105	1.020	4.011	3.0	5.0	7.0	9.0	11.0	11.0
3	145	0.87	3.395	2.0	4.0	6.0	8.0	10.0	10.0
4	195	0.75	2.910	2.0	4.0	6.0	8.0	10.0	10.0

[1] Starting weight for phases 2-4 are targets. Actual starting weight is based on end weight for the previous phase.
[2] Phase 4 ended with an average weight of 274 lbs.
[3] Diet 6 is equivalent to Diet 5 except that isoleucine and valine were corrected to NRC (2012) specifications.

Table 2a. Minimum level for SID Lysine and the next most limiting amino acids[1]

Diet Phase	Start Wt. lbs/pig	Diet SID Lysine, %	SID Lysine g/Mcal NE	SID ratio to SID Lysine M+C	THR	TRP	ILE	VAL
1	65	1.17	4.663	0.57	0.61	0.18	NO Minimum	NO Minimum
2	105	1.020	4.011	0.57	0.63	0.18		
3	145	0.87	3.395	0.57	0.65	0.18		
4	195	0.75	2.910	0.57	0.66	0.18		

[1] Specifications for methionine + cysteine (M+C), threonine (THR) , tryptophan (TRP) were based on NRC (2012). Isoleucine (ILE) and valine (VAL) levels were not controlled for diets 1-5 (see Table 3c).

Table 2b. Minimum profile for isoleucine (ILE) and valine (VAL).

		Diet 6 = Diet 5 + ILE, VAL		
Diet	Start Wt.		SID ratio : Lysine	
Phase	lbs/pig	Diet 6	Ile	Val
1	65	12.0	0.54	0.65
2	105	11.0	0.54	0.65
3	145	10.0	0.54	0.65
4	195	10.0	0.54	0.65

[1] Diet 6 is a duplicate of Diet 5, except that minimum ILE, VAL levels met NRC (2012) specifications.

Diet composition and nutrient specifications

Dietary lysine level was set at the requirement based on population response criteria for optimum profit (Zier-Rush et al., 2013b). Results of this internal study allowed us to formulate to a precise requirement, avoiding excess dietary lysine, which was essential for sensitivity in detecting excess SL content. Diets met or exceeded the standardized ileal digestible (SID) pattern for threonine, tryptophan and methionine + cysteine to SID lysine ratio, as specified by the NRC (2012). Ile and (or) Val were expected to be marginally deficient for the maximum SL dose (Diet 5; NRC, 2012). For this reason, Diet 6 was a duplicate of Diet 5, except that Ile and Val were added to prevent a possible deficit (NRC, 2012). The pattern for the 6 most limiting EAA is shown in **Tables 2a, b**.

Three diets (1, 5, 6) were manufactured with the control (low SL, Diet 1) and high SL (Diet 5) diets being summit mixed by the feed system to create Diets 2, 3 and 4. Dietary SBM content was reduced across all diets by the addition of a constant amount of CGM. Diets within each phase were formulated to meet the SID lysine to Mcal net energy (NE) specification shown in **Table 1**. Diet NE within each phase was made isocaloric by adjusting the fat level. NE values for energy-containing ingredients are shown in **Table 3a**. Diet composition is shown in **Table 3b** and calculated nutrient content is presented in **Table 3c**.

Since the study was conducted in a commercial environment, we also computed the productive energy (PE) value for diets by setting SBM PE = corn NE on a DM basis. Dietary PE was computed using the NE for all ingredients except as stated for SBM. This value was derived from studies on the energetic influence of dietary SBM under the commercial environment (Boyd and Gaines, 2023). The as-fed value for ingredient NE and PE was expressed based on the moisture level of the ingredients at the feed plant (Boyd and Gaines, 2023). The PE value was not a formula specification, but was an alternative dietary energy term that proved to be important to interpretation of the response to SL (**Table 3a**).

Dietary amino acid and fat levels were confirmed through chemical analyses (data not shown). Diet samples were acquired from feeders by treatment, rigorously mixed and subsampled. Amino acid analysis was replicated by 2 commercial labs.

Calculations, statistical analysis and planned comparisons

Since each pen was the experimental unit, performance was computed as pen average daily intake (ADFI), ADG and FCE (excluding removed pig weights). Data were analyzed using UNIVARIATE and GLM procedures of SAS. Gender was not a variable that could be statistically analyzed since sexes were separated into different barns, in accordance with management protocol (sex x barn confounded). Four planned comparisons were made: Linear and quadratic response forms; Diet 1 vs 6 and Diet 5 vs 6.

Table 3a. Net energy (NE) values for energy bearing ingredients that were used for diet formulation.

Ingredient	Feed Mill DM, % [1]	NE, mcal/kg DM basis, %	NE, mcal/kg As Is basis, %	PE, mcal/kg [2] As Is basis, %
Corn ground, CP 8.3 [3]	86.9	3.026	2.630	2.630
Corn Germ meal [4]	88.2	2.689	2.372	2.372
Wheat Midds, 22% Starch	87.8	2.459	2.159	2.159
Fat, CWG [5]	99.6	7.566	7.536	7.536
SBM, CP 47.5 [6]	87.9	2.432	2.138	2.660
L-Lysine	99.5	3.443	3.426	3.426
dL-Methionine	99.5	4.151	4.130	4.130
L-Threonine	99.5	2.965	2.950	2.950
L-Tryptophan	98.0	4.827	4.730	4.730
L-Isoleucine	90.0	4.966	4.469	4.469
L-Valine	96.5	3.568	3.443	3.443

[1] Ingredient NE (as-fed) are based on dry matter content specific to the feed mill.

[2] PE = Productive energy value applies to only SBM. Other ingredient PE values are their NE values. SBM PE estimate was set = 100% of corn NE, which was then adjusted for the difference in feed mill DM content for SBM compared to corn.

[3] Corn from 2013 crop, chemically analyzed to compute NE content using the NRC (2012) equation. Corn ground within the 575 to 625 microns and to meet specifications for mycotoxin content.

[4] Sourced from ADM, Decatur IL; NE estimate determined by internal growth assay.

[5] Choice white grease source analyzed to contain: <5.0% FFA, 1.45 unsaturate to saturate fatty acid ratio.

[6] SBM NE estimate from Cargill animal nutrition for ADM Decatur IL source plant.

Table 3b. Composition of the master blend Diets 1 and 5 and branch-chain corrected Diet 6 in lbs./ton [1]

	Phase 1			Phase 2			Phase 3			Phase 4		
Ingredient Name	**Fin 1**	**Fin 5**	**Fin 6**	**Fin 1**	**Fin 5**	**Fin 6**	**Fin 1**	**Fin 5**	**Fin 6**	**Fin 1**	**Fin 5**	**Fin 6**
Corn, 8.5 CP, 625 microns	981.4	1228.4	1220.5	1080.1	1329.3	1323.2	1169.6	1421.5	1416.9	1255.4	1507.5	1502.6
SBM, 47.0 CP	607	368	368	514	274	274	426	184	184	334	92	92
Corn Germ meal, ADM IL	200	200	200	200	200	200	200	200	200	200	200	200
Wheat Midds STL	100	100	100	100	100	100	100	100	100	100	100	100
Fat, CWG	60	34	36	60	33	34	60	33	33	65	38	38
L-Lysine.HCl	4.0	12.0	12.0	3.0	11.0	11.0	2.0	10.0	10.0	2.0	10.0	10.0
DL-Methionine	1.0	3.5	3.6	0.3	2.7	2.7		1.8	1.8		1.4	1.4
L-Threonine	0.6	4.1	4.1	0.4	3.9	3.9		3.4	3.4		3.5	3.5
L-Tryptophan	0	1.0	1.0		0.9	0.9		0.9	0.9		1.0	1.0
L-Valine			1.5			1.0			0.6			0.6
L-Isoleucine			1.2			1.1			1.0			1.3
Limestone	19.4	21.1	21.1	17.7	19.3	19.3	18.2	19.8	19.8	18.8	20.4	20.4
MonoCa Phos, 15.0:21.0	16.6	17.9	18.0	14.5	15.9	15.9	14.1	15.5	15.5	14.7	16.1	16.1
Salt	8.0	8.0	8.0	8.0	8.0	8.0	8.1	8.1	8.1	8.1	8.1	8.1
VTM Fin 2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Inert Food Color			3.0			3.0			3.0			3.0
Total lbs	**2000.0**	**2000.0**	**2000.0**	**2000.0**	**2000.0**	**2000.0**	**2000.0**	**2000.0**	**2000.0**	**2000.0**	**2000.0**	**2000.0**
Diet Cost, $/ton	**253.6**	**239.7**	**-**	**240.2**	**225.5**	**-**	**228.2**	**212.3**	**-**	**218.4**	**202.5**	**-**

[1] Diets 1 and 5 were blended by the Howeema feed system on the farm to create Diets 2, 3 and 4. Basis for ingredient cost is described in the financial evaluation section.

Pattern of dietary SBM content decline in the study

The maximum and minimum level of dietary SBM for each phase of growth is shown in **Figure 1**. In the first phase of growth, the highest level of SL (12 lbs./ton) reduced SBM content 39% compared to the control diet (4.0 lbs./ton). The net ingredient exchange involved displacing 239 lbs. of SBM and 27 lbs. of fat with 248 lbs. of corn and 21 lbs. of synthetic amino acids. SBM level for phase 2 diets was reduced by 47% when comparing the high and low SL diets. The SL dose range for phases 3 and 4 caused SBM to plummet to very low levels, representing a 57 and 72% displacement, respectively. A 5th diet is often used between 240 and 300 lbs. of body weight, which could reduce SBM to less than 50 lbs./ton, depending on how much corn coproducts are used. Seasoned nutritionists learned from commercial research that a very high SL level does not work in the final finishing stage; growth is impaired (personal communication, Dr. Aaron Gaines).

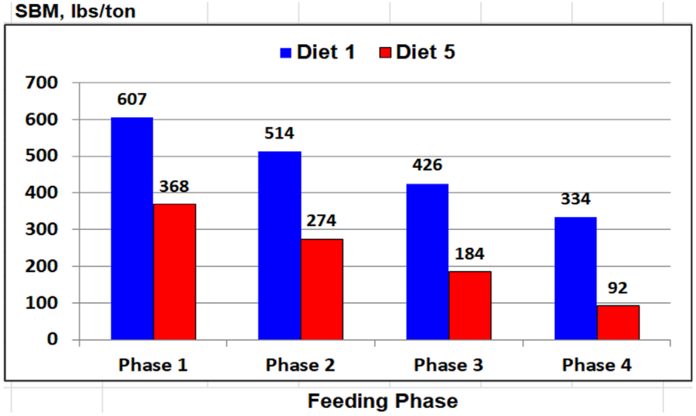


Figure 1. Dietary SBM content for the control (Diet 1) and maximum synthetic lysine (Diet 5) diets for each of the 4 feeding phases: 65-105, 105-145, 145-195, 195-270 lbs. end weight.

Table 3c. Calculated nutrient composition of master blend diets (1, 5) and branch-chain amino acid diet 6 [1, 2, 3]

		Phase 1			Phase 2			Phase 3			Phase 4		
Nutrient	**Unit**	**Fin 1**	**Fin 5**	**Fin 6**	**Fin 1**	**Fin 5**	**Fin 6**	**Fin 1**	**Fin 5**	**Fin 6**	**Fin 1**	**Fin 5**	**Fin 6**
Hanor Net Energy	Mcal/lb	2.505	2.498	2.501	2.530	2.521	2.522	2.549	2.540	2.542	2.581	2.572	2.570
Hanor Productive Energy	Mcal/lb	2.655	2.589	2.593	2.657	2.583	2.583	2.654	2.585	2.580	2.663	2.589	2.588
SID CP estimate	%	18.9	15.2	15.2	17.3	13.5	13.5	15.71	11.92	11.92	14.10	10.31	10.31
SID Lysine : SID CP	ratio	6.1	7.8	7.7	5.8	7.5	7.5	5.43	7.29	7.29	5.23	7.32	7.32
SID Lysine : NE	g/mcal NE	4.609	4.702	4.678	3.955	4.044	4.034	3.344	3.421	3.419	2.859	2.934	2.936
SID Lysine	%	1.15	1.17	1.17	1.00	1.02	1.02	0.85	0.87	0.87	0.74	0.75	0.75
SID Thr : Lysine	ratio	0.62	0.61	0.61	0.64	0.64	0.64	0.66	0.65	0.65	0.67	0.67	0.67
SID Trp : Lysine	ratio	0.198	0.182	0.182	0.203	0.180	0.180	0.21	0.183	0.183	0.21	0.185	0.185
SID Met +Cys : Lysine	ratio	0.57	0.57	0.57	0.58	0.58	0.58	0.62	0.58	0.58	0.65	0.58	0.58
SID Ile : Lysine	ratio	0.68	0.49	0.54	0.70	0.49	0.54	0.74	0.49	0.54	0.74	0.46	0.54
SID Val : Lysine	ratio	0.77	0.59	0.65	0.82	0.61	0.65	0.87	0.63	0.65	0.90	0.62	0.65
SID His : Lysine	ratio	0.45	0.35	0.35	0.47	0.36	0.36	0.51	0.37	0.37	0.53	0.37	0.37
SID Arg : Lysine	ratio	2.19	1.64	1.64	1.90	1.37	1.37	1.66	1.15	1.15	1.30	0.82	0.82
SID Leu : Lysine	ratio	1.38	1.12	1.10	1.48	1.18	1.18	1.62	1.26	1.26	1.72	1.31	1.31
SID Phe : Lysine	ratio	0.80	0.60	0.60	0.84	0.61	0.61	0.89	0.61	0.61	0.91	0.59	0.59
SID EAA	%	10.55	8.75	8.75	9.17	7.45	**7.45**	7.95	6.29	6.29	6.79	5.20	5.20
SID (NEAA, CEAA)/SID CP	ratio	0.44	0.42	0.42	**0.47**	**0.45**	0.45	**0.49**	**0.47**	**0.47**	**0.52**	**0.50**	**0.50**
STTD Ca	%	**0.41**	0.45	0.45	0.37	0.41	0.41	0.38	0.41	0.41	0.39	0.42	0.42
STTD P	%	0.33	0.33	0.33	0.30	0.30	0.30	0.29	0.29	0.29	0.29	0.29	0.29
Potassium	%	0.89	0.66	0.66	0.80	0.57	0.57	0.72	0.49	0.49	0.63	0.40	0.40

[1] Diet NE values vary slightly from the original publication (Zier-Rush et al., 2013b) because ingredient NE values were updated to compute diet NE. SBM NE was believed to be the most credible estimate at that time (Table 3a).

[2] SID, standardized ileal digestible amino acids or protein. SID protein was computed for each protein ingredients as the average for the amino acids that compose the respective protein. The SID lysine : SID CP ratio maximum was intended to not exceed 7.6 g lysine/100 g protein (digestible).

[3] Abreviations: CP, crude protein; EAA, essential amino acids; NEAA, non-essential amino acids; CEAA, conditionally essential amino acids.

Table 4. Growth response to diet SBM reduction by increasing synthetic lysine dose in 65 to 105 lbs phase

		Synthetic Lysine Dose										
Item	**Unit**	**Diet 1**	**Diet 2**	**Diet 3**	**Diet 4**	**Diet 5**	**Diet 6 Ile, Val**		**Probability, P=**			
Diet NE	mcal/kg	2.505	2.503	2.502	2.500	2.498	2.498					
Diet SBM content	lbs/ton	607	547	488	428	368	368		**Pre-planned Comparisons**			
Diet L-HCl content	lbs/ton	**4**	**6**	**8**	**10**	**12**	**12**	SEM	1 vs 6	5 vs 6	Linear, 1-5	Quad, 1-5
No. Pens	-	18	16	16	16	16	18	-	-	-	-	-
No. Pigs Placed	-	399	354	357	357	357	397	-	-	-	-	-
Initial Weight	lbs	65.3	66.0	65.8	65.8	65.8	65.3	1.00	0.997	0.726	0.782	0.729
Total gain	lbs/pig	38.8	38.8	39.1	39.0	39.8	40.5	-	-	-	-	-
Daily gain	lbs/d	2.04	2.05	2.06	2.05	2.09	2.13	0.02	0.004	0.251	0.096	0.584
Daily intake	lbs/d	4.02	4.04	4.07	4.11	4.23	4.25	0.05	0.002	0.820	0.001	0.261
Feed efficiency, FCE	lbs/lbs	1.97	1.97	1.98	2.00	2.02	1.99	0.02	0.258	0.183	0.006	0.353
NE Efficiency												
Gain:Mcal NE	lbs/mcal NE	0.446	0.447	0.446	0.440	0.436	0.442					
PE Efficiency												
Diet PE [1]	mcal PE/kg	2.657	2.639	2.620	2.602	2.583	2.583					
Gain:Mcal PE	lbs/mcal PE	0.421	0.424	0.426	0.422	0.422	0.428					

[1] Diet productive energy (PE) acquired from Table 3c.

Table 5. Growth response to diet SBM reduction by increasing synthetic lysine dose in 105 to 145 lbs phase[1]

		Synthetic Lysine Dose										
Item		Diet 1	Diet 2	Diet 3	Diet 4	Diet 5	Diet 6	Ile, Val	**Probability, P=**			
NE diet	mcal/kg	2.530	2.528	2.526	2.523	2.521	2.521					
SBM	lbs/ton	514	454	394	334	274	274		**Pre-planned Comparisons**			
L-HCl	lbs/ton	**3.0**	**5.0**	**7.0**	**9.0**	**11.0**	**11.0**	SEM	1 vs 6	5 vs 6	Linear, 1-5	Quad, 1-5
Initial Weight	lbs	104.1	104.8	104.9	104.8	105.6	105.8	1.3	0.331	0.903	0.410	0.989
Total gain	lbs/pig	42.0	43.2	42.0	42.3	42.5	42.7	-	-	-	-	-
Daily gain	lbs/d	2.12	2.16	2.11	2.11	2.13	2.12	0.02	0.765	0.942	0.669	0.941
Daily intake	lbs/d	5.31	5.35	5.31	5.35	5.39	5.46	0.05	0.044	0.348	0.344	0.618
Feed efficiency, FCE	lbs/lbs	2.51	2.49	2.52	2.53	2.53	2.57	0.02	0.062	0.268	0.149	0.659
NE Efficiency												
Gain:Mcal NE	lbs/mcal NE	0.348	0.352	0.347	0.345	0.345	0.339					
PE Efficiency												
Diet PE ^{2}	mcal PE/kg	2.657	2.638	2.620	2.601	2.583	2.583					
Gain:Mcal PE	lbs/mcal PE	0.331	0.337	0.334	0.334	0.337	0.331					

[1] Number of pens per treatment and pigs per pen are shown in Table 4.

[2] Diet productive energy (PE) acquired from Table 3c.

Table 6. Growth response to diet SBM reduction by increasing synthetic lysine dose in 145 to 195 lbs phase[1]

		Synthetic Lysine Dose										
Item	Unit	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5	Diet 6	Ile, Val	**Probability, P=**			
NE diet	mcal/kg	2.549	2.547	2.545	2.542	2.540	2.540					
SBM	lbs/ton	426	366	305	245	184	184		**Pre-planned Comparisons**			
L-HCl	lbs/ton	**2.0**	**4.0**	**6.0**	**8.0**	**10.0**	**10.0**	SEM	1 vs 6	5 vs 6	Linear, 1-5	Quad, 1-5
Initial Weight	lbs	146.1	148.0	146.9	147.1	148.1	148.5	1.9	0.223	0.867	0.453	0.942
Total gain	lbs/pig	47.5	47.3	46.5	45.9	44.3	44.6	-	-	-	-	-
Daily gain	lbs/d	2.25	2.25	2.21	2.19	2.13	2.14	0.03	0.002	0.943	0.001	0.348
Daily intake	lbs/d	6.35	6.40	6.35	6.39	6.41	6.28	0.07	0.466	0.171	0.591	0.895
Feed efficiency, FCE	lbs/lbs	2.82	2.84	2.87	2.91	3.00	2.94	0.02	<0.001	0.033	<0.001	0.059
NE Efficiency												
Gain:Mcal NE	lbs/mcal NE	0.306	0.304	0.301	0.297	0.288	0.296					
PE Efficiency												
Diet PE ^{2}	mcal PE/kg	2.654	2.636	2.617	2.599	2.581	2.581					
Gain:Mcal PE	lbs/mcal PE	0.294	0.294	0.293	0.291	0.284	0.291					

[1] Number of pens per treatment and pigs per pen are shown in Table 4.

[2] Diet productive energy (PE) acquired from Table 3c.

Dietary synthetic lysine dose response in early growth

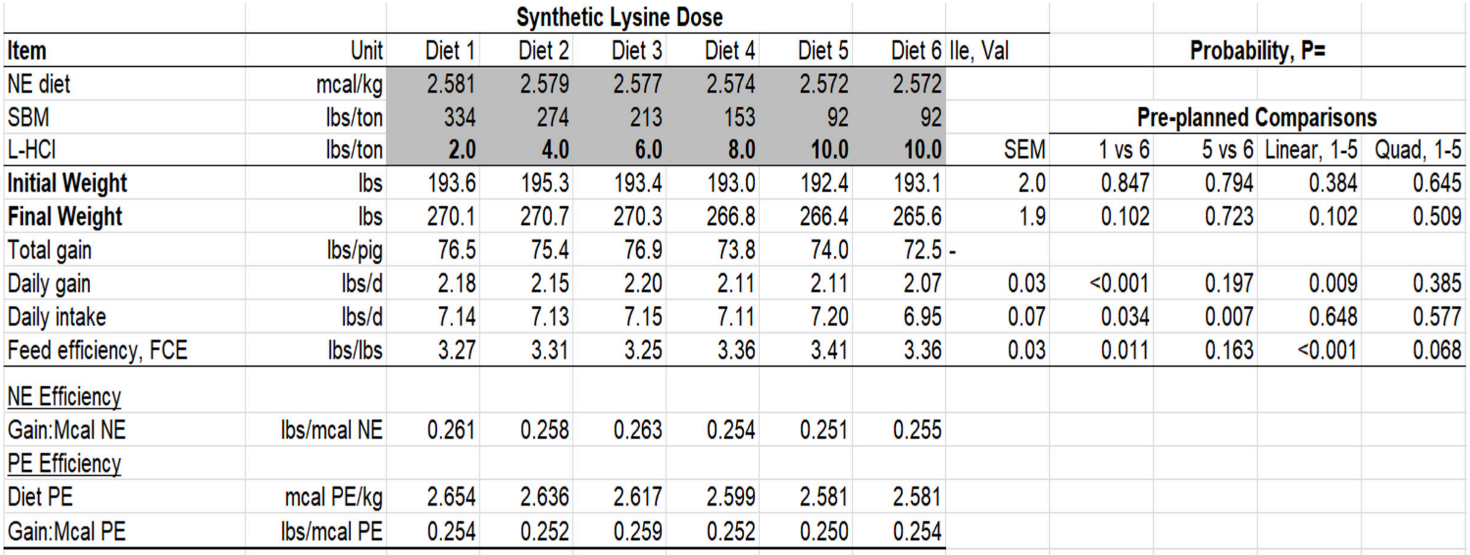
Early growth (65 to 145 lbs.)

In general, relatively high dietary levels of SL (10-11 lbs./ton) did not affect either rate or efficiency of growth during the early phases for growing–finishing pigs (**Tables 4, 5**). A subtle erosion in FCE was observed during the 65 to 105 lbs. phase (linear effect, P=0.006; **Table 4**), despite the diets having been formulated to be isocaloric (NE basis). However, the gentle erosion in FCE coincided with a reduction in dietary PE as SBM content declined. A linear increase in ADFI was observed with declining diet PE content (P=0.001). This may reflect an attempt by the pig to maintain constant caloric intake as diet PE declined.

The increase in FCE and ADFI is most likely due to declining dietary PE and not to excess SL (12 lbs./ton). The relative change in growth and FCE (-2.45%, +2.54% respectively) were similar to the decline in dietary PE from Diets 1 to 5 (-2.86%). This conclusion is supported by the fact that weight gained per mcal PE intake was constant even though dietary PE declined (0.423 lbs. gained/Mcal PE intake, **Table 4**).

Pigs in the 105 to 145 lbs. phase of growth performed normally on a diet containing up to 11 lbs. SL/ton (**Table 5**). Growth rate was not altered by SL dose (P=0.669) and FCE also held constant to the maximum SL dose (P=0.149). Both responses varied by less than 1% (Diet 1 vs 5) despite a numeric decline in diet PE (2.657 vs 2.583 Mcal PE/kg). The measure, Mcal PE

Table 7. Growth response to diet SBM reduction by increasing synthetic lysine dose in 195 to 270 lbs phase



		Synthetic Lysine Dose										
Item	Unit	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5	Diet 6	Ile, Val		**Probability, P=**		
NE diet	mcal/kg	2.581	2.579	2.577	2.574	2.572	2.572					
SBM	lbs/ton	334	274	213	153	92	92		**Pre-planned Comparisons**			
L-HCl	lbs/ton	**2.0**	**4.0**	**6.0**	**8.0**	**10.0**	**10.0**	SEM	1 vs 6	5 vs 6	Linear, 1-5	Quad, 1-5
Initial Weight	lbs	193.6	195.3	193.4	193.0	192.4	193.1	2.0	0.847	0.794	0.384	0.645
Final Weight	lbs	270.1	270.7	270.3	266.8	266.4	265.6	1.9	0.102	0.723	0.102	0.509
Total gain	lbs/pig	76.5	75.4	76.9	73.8	74.0	72.5	-				
Daily gain	lbs/d	2.18	2.15	2.20	2.11	2.11	2.07	0.03	<0.001	0.197	0.009	0.385
Daily intake	lbs/d	7.14	7.13	7.15	7.11	7.20	6.95	0.07	0.034	0.007	0.648	0.577
Feed efficiency, FCE	lbs/lbs	3.27	3.31	3.25	3.36	3.41	3.36	0.03	0.011	0.163	<0.001	0.068
NE Efficiency												
Gain:Mcal NE	lbs/mcal NE	0.261	0.258	0.263	0.254	0.251	0.255					
PE Efficiency												
Diet PE	mcal PE/kg	2.654	2.636	2.617	2.599	2.581	2.581					
Gain:Mcal PE	lbs/mcal PE	0.254	0.252	0.259	0.252	0.250	0.254					

[1] Number of pens per treatment and pigs per pen are shown in Table 4.
[2] Diet productive energy (PE) acquired from Table 3c.

required per unit of gain, suggested that the small numeric drift in FCE was likely due to declining PE and not to excessive SL content. Gain achieved per Mcal PE intake was remarkably constant across the 5 diets (average, 0.335 lbs. gain/Mcal PE).

To this point (65 to 145 lbs.), the addition of Ile and Val to Diet 6 did not improve growth or FCE, despite levels in Diet 5 appearing to be marginally deficient (0.49%, 0.60% respectively; NRC, 2012).

Dietary synthetic lysine dose response in mid-finish growth

Transition from growing to finishing (145 to 195 lbs.)

The 'transition' stage to finishing was a turning point in the pigs' response to SL level. The maximum SL dose (10 lbs./ton) impaired growth and FCE (**Table 6**). The erosion was manifested by 8 lbs. SL/ton of diet (linear, P<0.001), despite meeting the minimum ideal amino acid profile (NRC, 2012) and represents a 30% reduction in SL from the early phases (65-145 lbs.). This limit to SL use has been a recurring problem for nearly 25 years, even though the commercial amino acid library has tripled and despite a marked increase in our knowledge of EAA requirements. Several nutritional nuances have also been addressed, but the 'barrier' to high SL use in diets after 150 lbs. body weight remains (Boyd et al., 2024).

Despite diets being isocaloric (NE basis), both FCE and growth rate declined as SL content increased (linear, P<0.001). This coincided with a decline in dietary PE content (-2.85%; Diets 1 to 5), but the erosion in FCE (+6.38%) and growth rate (+5.63%) were greater than expected from the decline in diet PE. PE content was predictive of the erosion in growth and FCE, but appeared to underpredict the magnitude of change. On the other hand, dietary NE did not predict the decline in performance because it was constant across diets. Although PE appears to be the more appropriate measure for this commercial study, it is unlikely that diets formulated to be isocaloric for PE would correct the variance for FCE or growth.

As noted for the previous growth period (65 to 145 lbs.), the addition of Ile and Val to diet 6 did not restore growth or FCE to the control level (Diet 1 vs 6; P<0.002), despite levels in Diet 5 appearing to be marginally deficient (SID 0.488%, 0.625% respectively). Assuming that the NRC minimum for the SID histidine to lysine ratio is correct (0.344), it would not have been a limiting factor (Diet 5, 0.37%; **Table 3b**).

The abrupt reduction in dietary SL content that is required to prevent impaired growth would not be resolved by diet equivalence for PE content, and meeting or exceeding the requirement for all EAA was not beneficial.

Dietary synthetic lysine dose response in late-finish growth

Late-finishing (195 to 270 lbs.)

The response of late-finishing pigs to increasing SL dose was similar to the previous phase (145 to 195 lbs.), in that 8.0 lbs. SL/ton of diet coincided with impaired growth and FCE (**Table 7**). The rate of gain declined as dietary SL content increased (linear, P=0.009), and the addition of Ile and Val did not improve the response. FCE erosion followed a similar pattern with SL dose (linear, P<0.001).

The decline in dietary PE content (-2.85%) coincided with an erosion in FCE (+4.28%) and growth (-3.32%), when comparing the response of pigs fed Diet 5 (10.0 lbs/ton SL) to those fed Diet 1. It is not clear whether diets formulated to be isocaloric for PE would resolve the decline in growth rate, but it is unlikely that FCE would be restored because the difference from the control (+4.28%) was 14 points in FCE (3.27 vs 3.41). Reformulating diets to be PE equivalent would require an additional 28 lbs. of fat, but this would improve FCE by only 8 to 9 points (Elsbernd et al., 2016).

The addition of Ile and Val did not improve growth and FCE for this or other phases of growth. Dietary histidine (His) level exceeded the NRC (2012) minimum for Diet 5 of every phase (**Table 3c**) and phenylalanine (Phe) also met the minimum specification (NRC, 2012). Having supplemented diets with the 6 most limiting amino acids, we believe that the requirement was met for all EAA because the remaining amino acids either met (His, Phe) or significantly exceeded (arginine, leucine) the NRC (2012) minimum level. We do not anticipate that either NEAA or CEAA were deficient based on levels shown in **Table 3c**.

What was learned?

Results of the 2 early phases (65 to 145 lbs.) confirmed that 11-12 lbs. of SL could be used in diets without impairing growth (**Tables 4, 5**). It appears that diets formulated to be isocaloric for PE, rather than NE, would allow for slightly greater SL levels without eroding growth or FCE. Describing commercial diets by PE, rather than NE, appears to improve the accuracy of diet energetic value. PE calculation simply required the adjustment of SBM NE to be equal to corn. This is consistent with our research in commercial environments (Boyd and Gaines, 2023).

Results for the 2 later phases of growth (145 to 270 lbs.) confirmed that the ‘barrier’ to high SL use after 150 lbs. body weight remains (**Tables 6, 7**), but this is consistent with studies conducted by Hanor and findings of several companies over the past 25 years. The erosion in growth that resulted from feeding diets with high SL content reiterates the need to determine the maximum SL dose after 150 lbs., through empirical study. Although formulating diets to be isocaloric for PE is also important for later growth, the departure in performance for pigs fed a high SL level (Diet 5 vs Diet 1) was too large to be resolved by application of PE.

We learned that growth was impaired after 150 lbs. even though the ideal amino acid profile was met for all EAA. It seems unlikely that NEAA were limiting as the sum of NEAA + conditionally EAA (CEAA) represented 52-54% of the total CP (**Table 3c**). Collectively, these findings suggest that something other than dietary PE level and amino acid nutrition was constraining growth with extensive displacement of SBM by synthetic amino acids and corn.

It is conceivable that the erosion in growth and FCE (phases 3, 4) is not due to a nutritional factor, but to an extreme loss of functional compounds (e.g., isoflavones, ISF) that are contained in SBM. These function to improve health, metabolic function and ultimately, growth (Petry et al., 2024; White et al., 2024). In the first 2 phases of growth, SBM content in Diet 5 was 61% and 53% of the control (Diet 1), respectively. In the final 2 phases, SBM content in Diet 5 was only 43% and 28% of their respective control diet (**Figure 1**).

This decline in ISF alone is extensive; declining from ca. 386 ppm in phase 1 to 287, 193 and 96 in phases 2, 3 and 4, respectively. Corn and amino acids do not provide similar levels of ISF and other functional compounds found in SBM (Boyd et al., 2023).

Finally, the results of this study are applicable to healthy pigs, reared in a commercial environment. Minimum dietary SBM levels that should be fed during swine respiratory disease stress are higher (Boyd et al., 2023).

Maximum profit synthetic lysine level by growth phase

Choice of the maximum SL level to use for each phase is a financial decision and involves more than simply lowest diet cost. A partial financial calculation relates total input cost (diet, housing) required to generate equivalent weight gain. We used growth data from **Tables 6 and 7** to identify the most profitable SL level for transition and late-finishing phases (**Table 8**). Data

Table 8. Partial financial evaluation for optimum profit synthetic lysine level for growing pigs from 145 to 270 lbs. body weight (phases 3, 4)

Input cost (feed, housing) required to create equivalent gain (data from tables 6, 7)

		Synthetic Lysine Dose				
Item	**Unit**	**Diet 1**	**Diet 2**	**Diet 3**	**Diet 4**	**Diet 5**
Phase 3, 145-195 lbs.						
Synthetic Lysine Dose	lbs/ton	**2**	**4**	**6**	**8**	**10**
Diet Cost, $/ton [1]	$/ton	228.2	224.2	220.2	216.3	212.3
Feed Cost of gain	$/lb gain	0.3218	0.3184	0.3160	0.3147	0.3184
Feed Cost, 48 lbs gain	$/48 lbs gain	15.44	15.28	15.17	15.10	15.28
Marginal Gain vs Diet 1	lbs/pig	-	-	-1.0	-1.6	-3.2
Marginal Feed + Housing [2]	$/48 lbs gain	15.44	15.28	15.24	15.21	15.50
Phase 4, 195-270 lbs.						
Synthetic Lysine Dose	lbs/ton	**2**	**4**	**6**	**8**	**10**
Diet Cost, $/ton [1]	$/ton	218.4	214.4	210.4	206.4	202.5
Feed Cost of gain	$/lb gain	0.3570	0.3548	0.3419	0.3468	0.3452
Feed Cost, 76 lbs gain	$/76 lbs gain	27.14	26.97	25.99	26.36	26.23
Marginal Gain vs Diet 1	lbs/pig	-	-	-	-2.7	-2.5
Marginal Feed + Housing [2]	$/76 lbs gain	27.14	26.97	25.99	26.54	26.40

[1] Diet cost shown in Table 3b for Diets 1 and 5. Diets 2, 3, 4 computed from summit blend rate.

[2] Housing cost computed as $0.12/d

from the early growth phases were not processed, because growth was not 'significantly' affected by the highest SL dose used (**Tables 4, 5**).

Ingredient prices for the July to August 2024 time frame were applied to the original formulation, with the exception of fat where the price was set equal to 3 times the corn price. Fat was added to keep diets isocaloric (NE basis) for the study (2013), but present fat price is too extreme for NE equivalence.

For the transition growth phase (145 to 195 lbs.), diet cost declined by about $4.00 per ton for each step in SL dose. Dietary SBM declined by 60 lbs. for each SL diet step (**Table 8**). Feed cost (FC) to produce equivalent gain (48 lbs.) suggests that we could use up to 8.0 lbs. of SL/ton before total FC started to increase. When the additional housing cost was included to deliver equivalent gain (1 to 2 d), a slight numerical advantage favored 6 lbs. SL/ton. This might be ignored if the extra time required for equivalent gain is less than 5 to 7 d. The exception would be summer marketing, when time is often a constraint.

Calculations for late-growth (195 to 270 lbs.) show a profitability limit at 6.0 lbs. SL/ton, because the FC to produce equivalent gain (76.0 lbs.) was lowest at that point. This level is considerably lower than used by some commercial nutritionists. Most of the time, they have not conducted SL response studies and believe that high diet SL content (e.g., 10-13 lbs./ton) does not impair growth provided that the ideal pattern for EAA is met (personal communication, Dr. Aaron Gaines).

Identifying maximum profit diets requires relating diet cost to animal performance. Least-cost diets seldom lead to maximum profit. In the process of minimizing diet cost, profit is improved, but further cost reductions may reverse course to reduce profit. Profit maximization analysis occurs outside of formulation, where diet cost is compared to the value it created. Value is measured as carcass weight, full-value pigs (number) and cull pig revenue (Borg, July 2024).

Refining principles and paradigm shift

Seasoned commercial nutritionists would not be surprised by these results. The sudden limit or 'wall' to high SL use after about 150 lbs. is consistent with private sector studies that date back 25 years.

Some novel findings emerged from this study, which helped refine our understanding of commercial diet energetics. The energy term must predict both direction and quantitative changes in FCE and ADG, in order to be useful. Dietary PE, rather than NE, predicted the departure in response that was observed as SL content increased for the transition (145 to 195 lbs.) and late-finishing phases (**Tables 6 and 7**).

Serial removal of SBM resulted in declining dietary PE, which coincided with FCE loss. Diet NE, on the other hand, was predicted to increase as SBM was replaced by corn and amino acids. In reality, SBM removal reduced useable dietary energy and fat removal (to keep NE constant) likely made it worse. Thus, we see that SBM improves total diet energetics in the commercial setting. The concept that dietary PE term was the better predictor of FCE erosion is portrayed in **Figure 2**. This is the basis for our shift in perspective that SBM improves diet energy value in the commercial setting.

Is impaired growth from SBM removal due to declining CP or SBM level?

Many factors are in motion when SBM is replaced by corn and amino acids. Serial reductions in diet SBM and the resulting CP content were systematically studied in a foundational paper on low dietary protein research (Johnston et al., 1999; Boyd et al., 2024). This study was conducted more than 25 years ago, but it has never been more relevant. The authors skillfully controlled many of the variables suggested today for our inability to reduce CP by 4.0% or more without impairing growth and FCE. The results suggested that, at some point in the synthetic amino acid library expansion, something other

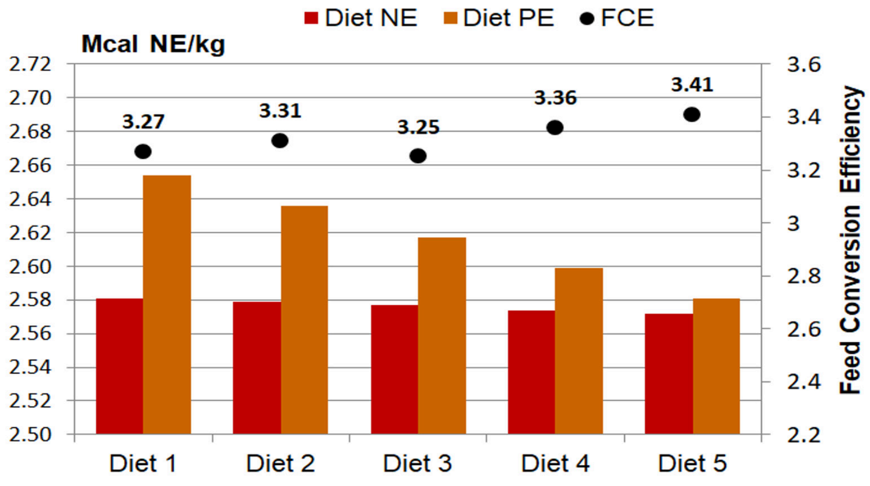


Figure 2. Diet productive energy (PE) rather than net energy (NE) was predictive of FCE departure from the control diet (195 to 270 lb. phase of growth).

Serial removal of SBM for Diets 1-5 resulted in declining dietary PE and consequently FCE loss. Diets 1-5 were formulated to be constant on an NE basis (2596 mcal NE/kg). Data acquired from Table 7.

than amino acids (EAA, NEAA, CEAA) might become first limiting to growth by the modern high lean growth pig.

This foundation study reduced SBM content by up to 90%, which was replaced by corn and every EAA that was removed in the process. NEAA nitrogen and CEAA (cysteine, tyrosine) were also completely restored. Potassium loss by SBM removal was held to a level that significantly exceeded the NRC (2012) minimum and DEB was corrected to counter significant increases in chloride ion content from lysine and arginine sources. Diet NE for that study was recalculated using ingredient NE values from the NRC (2012), and recent estimates for SBM (Boyd and Rush, 2018; Lee et al., 2022) and for all 15 crystalline amino acids that were added to the diet (Rostagno et al., 2017).

Four important conclusions were emphasized by the Boyd, Usry and Austic team (Boyd et al., 2024):

1. There was a point in SBM depletion when growth became impaired even though every EAA, NEAA and CEAA was restored to match the reference diet.
2. Dietary protein could only be reduced to a point (2.5% to 3.5% CP) without impairing growth.
3. Impaired growth manifested as FCE erosion, which was the result of pigs becoming fatter.
4. At some point in SBM depletion, something other than amino acids became first limiting to expression of genetically normal growth.

Ultimately, we concluded that the limiting factor to normal growth was either (1) failure to provide a minimum of dietary protein for some biological benefit, or (2) substitution of one protein ingredient that was rich in non-nutrient factors with another that is inferior in its content; non-nutrient factors that may influence pig health and (or) ability to express their genetic capacity for growth.

We hypothesized that the limiting factor was not intact protein, per se; rather, that SBM (legume protein sources) have complementary nutrient factors (CNF; functional components) that are capable of improving the extent to which the genetic capacity for growth is expressed. This expression in the commercial environment has been estimated to be < 35% (personal communication, Steve Jungst, research geneticist, retired). In other words, protein sources can be made equal for amino acid and energy value, but have significant differences in their content of growth and health promoting CNF (Petry et al., 2024; White et al., 2024). SBM is a rich source of both.

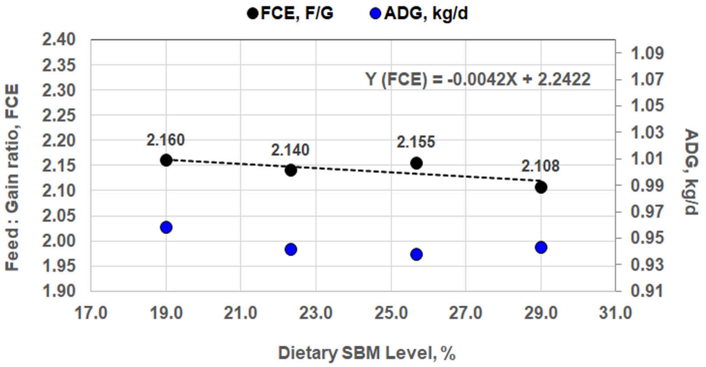
SBM PE is evidence of complementary nutrient benefit

The growth-impairing effect of ‘extremely low’ dietary SBM levels for growing (85 to 161 lbs.) and finishing pigs (183 to 275 lbs.) was reported by van Heugten (2024). Gain and FCE responses appeared to improve as a function of dietary SBM content. This agrees with our observations during the transition (**Table 6**) and late-finishing phases (**Table 7**). In both studies, CP level increased as SBM increased, so this confounding of dietary variables prevented us from distinguishing between SBM and CP content as the limiting factor.

The possible involvement of the CNF of SBM is suggested by how pigs responded to increased increments of SBM. The extra-caloric effect of SBM (described as PE) is evidence for a physiological benefit that is greater than expected based on known principles for nutrient effects. We reported that the PE response by SBM in the commercial environment was 26% greater than expected from classic substrate-derived NE (Boyd and Gaines, 2023). This involved a straight-forward energetic test with growing pigs (**Figure 3**).

Figure 3. Growth assay suggests SBM apparent NE is greater than corn.

Growth data was provided courtesy of Dr. Gary Stoner, VP Nutrition, R&D for the C.P. [Charoen Pokphand] group, China. The straight-forward growth assay, involving the exchange of SBM for corn (and amino acids), caused diet FCE to improve for growing pigs in a commercial environment (21 d; 104-148 lbs.). See Boyd and Gaines (2023) for detail.



Mechanism of action for improved growth, FCE and viability in pigs will take some time to link to performance outcome (Petry et al., 2024), but the influence of dietary SBM content on these criteria is abundant. If a minimum amount of SBM is needed to maximize growth (van Heugten, 2024), then it is noteworthy to understand that the modern pig has been selected for high lean growth rate for more than 35 years and SBM has been the major protein fed during this transformational period.

Key Conclusions

1. Synthetic lysine (SL) cannot be used without performance-proven dietary limits, even though the ideal amino acid pattern is met for all essential amino acids.

2. In commercially-reared pigs, more SL can be fed up to about 150 lbs. body weight (e.g., 10-12 lbs. per ton) than in later growth phases (>150 lbs.).

3. Profitability of a least-cost diet can only be known by comparing feed input cost to the value of carcass weight produced.

4. These results are applicable to healthy, commercially reared pigs. Pigs challenged by respiratory disease are expected to be much more sensitive to SBM displacement (Boyd et al., 2023).

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Reference Information

1. Boyd, R.D., M. Johnston, J. Usry and R.E. Austic. 2024. Foundation study for low protein diet research: SBM depletion impaired growth in pigs despite restoration of all essential amino acids and non-essential amino acid nitrogen. Feedstuffs, April digital edition, page 1. https://informamarkets.turtl.co/story/feedstuffs-april-2024/page/2/1.
2. Petry, A., B. Bowen, L. Weaver and R. Dean Boyd. 2024. Functional compounds in soybean mean: implications for pig health and physiology. Feedstuffs, February digital edition, page 1. https://informamarkets.turtl.co/story/feedstuffs-february-2024/page/5/1
3. Zier-Rush, C., M. McGrath, M. McCulley. R. Palan, J. Picou, K. Touchette and R.D. Boyd. 2013a. Performance response for increasing crystalline lysine in finishing pig diets: Most profitable maximums by phase differ from best FCE maximums. Hanor Tech. Memo. 2013-14 IL. https://dx.doi.org/10.13140/RG.2.2.11454.29767
4. Zier-Rush, C., D.S. Rosero, C. Neil, S. Jungst and R.D. Boyd. 2013b. Financial optimum lysine curves determined on a population basis for growing PIC pigs (45 to 300 lbs. BW). Hanor Res. Memo. 2013-07. http://dx.doi.org/10.13140/RG.2.2.18165.18402
5. National Research Council (NRC). 2012. Nutrient requirements of swine 11th revised edition. National Academy Press, Washington, DC, USA. https://doi.org/10.17226/1329
6. Boyd, R.D. and A.M. Gaines. 2023. Soybean meal NE value for growing pigs is greater in commercial environments. Feedstuffs, August digital edition, page 1. https://informamarkets.turtl.co/story/feedstuffs-august-2023/page/2/1
7. National Research Council (NRC). 2012. Nutrient requirements of swine 11th revised edition. National Academy Press, Washington, DC, USA. https://doi.org/10.17226/1329
8. Boyd, R.D., M.E. Johnston, J. Usry, P. Yeske and A. Gaines. 2023. Soybean meal mitigates respiratory disease-impaired growth in pigs. Feedstuffs, October digital edition, page 1. https://informamarkets.turtl.co/story/feedstuffs-october-2023/ page/2/1
9. Boyd, R.D. and C. Rush. 2019. Estimation of soybean meal NE for healthy growing pigs in the commercial environment by the Snyder feed efficiency growth assay. Hanor Memo. 2019-00. Access via Research Gate, R. Dean Boyd under Technical Reports
10. Boyd, R.D. and A.M. Gaines. 2023. Soybean meal NE value for growing pigs is greater in commercial environments. Feedstuffs, August digital edition, page 1. https://informamarkets.turtl.co/story/feedstuffs-august-2023/page/2/1
11. Boyd, R.D. and C. Rush. 2018. Estimation of soybean meal NE for healthy growing pigs in academic-equivalent environment by the Snyder feed efficiency growth assay. Hanor Memo. 2018-00. Access via Research Gate, R. Dean Boyd under Technical Reports
12. Johnston, M.E., J.L. Usry and R.D. Boyd. 1999. Effect of feeding low protein diets on performance of growing pigs. J. Anim. Sci. 77 (Suppl.1):69.
13. Lee, S.A., D.A. Rodriguez and H.H. Stein. 2022. Net energy in U.S. soybean meal fed to group-housed growing pigs is greater than calculated book values. 15th Int. Symp. Diges. Physio. Pigs. Anim., Sci. proc. 13 (Issue 2):178.
14. Rostagno, H.S. et al., 2017. Brazilian tables for poultry and swine: Composition of feedstuff and nutritional requirements. 4th ed. Dep. Zootecnia, Univ. Fed. Vicosa MG.
15. Elsbernd, A., C.E. Zier-Rush, D. Rosero, M. Hatcher, R. Palan, J. Picou and R.D. Boyd. 2016. Determining the optimum fat level under summer heat stress in finish pigs: defining response relationships for financial evaluation. Hanor Tech. Memo. H 2016-02 IL. http://dx.doi.org/10.13140/RG.2.2.35781.26
16. White, C.S., L.E. Froebel and R.N. Dilger. 2024. A review on the effect of soy bioactive components on growth and health outcomes in pigs and broiler chickens. J. Anim. Sci.102. https://doi.org/10.1093/jas/skae261
17. Borg, B. 2024. What does this all mean for swine diet formulations? Iowa Swine Day Pre-conference symposium. https://www.ipic.iastate.edu/iowaswineday/program.html, Oral presentation. https://www.youtube.com/watch?v=3cL7FW_WZeA
18. van Heugten, E. 2024. Increased dietary inclusion of soybean meal improves gain and feed efficiency of healthy finishing pigs. Feedstuff, September digital edition, page 1. https://informamarkets.turtl.co/story/feedstuffs-august-2024/page/18