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This article is the 10th in a series highlighting the unique value of soybean meal to swine nutrition and health

New Finding in Animal Growth: Dietary Soybean Meal Content is Important for Maximum Growth Expression by Pigs in the Commercial Environment

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Introduction

Soybean meal (SBM) is a remarkable amino acid source that has been a staple in swine diets for more than 50 years. Our understanding of SBM value has recently expanded to include an ability to mitigate viral suppression of growth in a dose-dependent manner (Boyd et al., 2023). We also observed that dietary SBM level was positively related to the ability of weaned pigs to thrive with less medical need when they encountered a viral infection (Petry et al., 2024). We believe that this is due to functional compounds that legumes, especially SBM, contain in abundance (Petry et al., 2024). These may serve a complementary physiological role to the energy and nutrient fraction by improving metabolic outcomes (Boyd et al., 2024a).

Until recently, swine nutritionists believed that alternative proteins to SBM could be made equivalent by correcting their amino acid deficits. However, maximum growth and feed conversion efficiency (FCE) cannot be achieved in the commercial environment without a 'certain' level of SBM. This advance in knowledge is the result of research by van Heugten (2024), who was the first to report that growth rate and FCE in healthy pigs was dependent on dietary SBM level. He observed this relationship for both growing (85 to 161 lbs.) and finishing pigs (183 to 275 lbs.) with 2 diet formats – simple corn, SBM, amino acids diet (C-S) and one that included corn distiller's dried grains with solubles (DDGS).

The possibility that growth expression can be increased by SBM prompted us to review data from our previous publication involving incremental removal of SBM from diets fed to pigs in a commercial setting (Boyd et al., 2024b). We confirmed the dependency of maximum growth rate and FCE on dietary SBM content. Our diet framework and treatment design allowed us to extend these findings by estimating the minimum SBM content needed to maximize growth and FCE for each feeding phase (24 to 295 lbs. body weight) for pigs in the commercial environment.

The ability to improve growth rate of healthy pigs (without clinical signs of disease) with a specific SBM level is a new finding in animal growth expression. This is important knowledge for the commercial sector when growth rate is at a premium.

SBM Improves Growth Expression

Van Heugten (2024) observed that growth expression was related to dietary SBM content, an outcome they had not anticipated for pigs of high-health status. Two growth studies were conducted that involved a step-wise displacement of SBM with corn and synthetic lysine (0, 4, 8, 12 lbs./ton) to determine if there was a level of SBM displacement that would impair growth. Diet comparisons involved a simple corn-SBM (C-S) format with amino acids incrementally displacing SBM and a second dietary format having a fixed level of DDGS (25%) to reduce dietary SBM content further. The first study involved the growing phase (85 to 161 lbs.) with dietary SBM content ranging from 6% to 21%. The second study involved the finishing phase (183 to 275 lbs.) with pigs fed diets ranging from 0% to 20% SBM. Studies were conducted during non-summer months with pigs being of high health status (absence of clinical disease).

Each diet format provided a 4-point crystalline lysine (L-HCl) response curve with a total of 8 response points for gain and FCE (4 from C-S diets, 4 from DDGS diets). The pattern that emerged was better understood when the response was related to dietary SBM content rather than L-HCl. The same response pattern emerged for pigs in both growing and finishing phases. The response during the finishing period is shown in **Figures 1** and **2**. Increasing dietary SBM content was associated with improvements in weight gain (R^2 = 0.641) and FCE (R^2 = 0.594). These results are similar to those for the growing phase (R^2 = 0.454, 0.732 respectively). In general, total live weight gain and FCE improved (linear, P<0.05) as dietary SBM level increased, regardless of DDGS inclusion (diet format interaction, P>0.16).

Figure 1. Total weight gained in response to increasing SBM content during the finishing phase (37 d; 183 to 275 lbs.); adapted from Figure 11 of van Heugten, 2024. Pigs fed corn–SBM (black circle) or corn, SBM and 20.0% DDGS (red circle). DDGS effect, P=0.046; DDGS (or no DDGS) x L-Lysine level interaction, P=0.167. Diet SBM level declined by adding 0, 4, 8 or 12 lbs. L-Lysine HCl/ton.

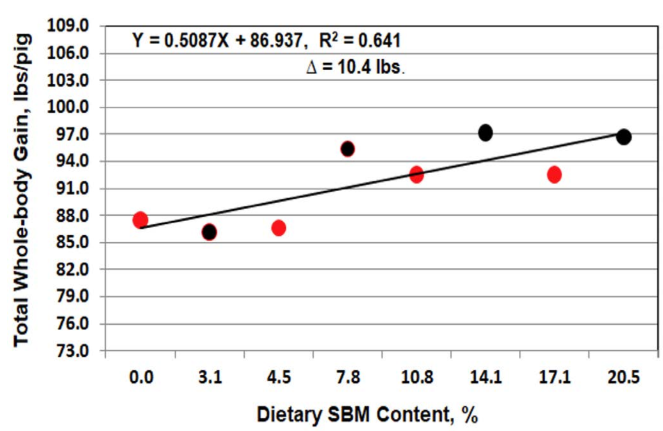
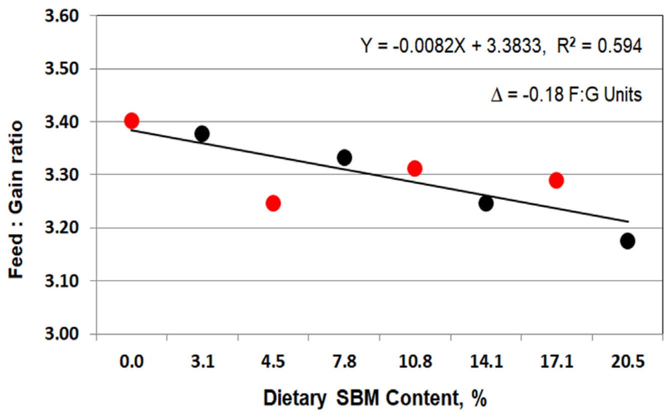


Figure 2. Feed conversion efficiency in response to increasing SBM content during the finishing phase (37 d; 183 to 275 lbs.); adapted from Figure 12 of van Heugten, 2024. Pigs fed corn–SBM (black circle) or corn, SBM, 20.0% DDGS (red circle). SEM = 0.044. DDGS effect, P=0.425; DDGS (or no DDGS) x L-Lysine level interaction, P=0.133. Diet SBM level declined by adding 0, 4, 8 or 12 lbs. L-Lysine HCl/ton.



The regression response for finishing pigs showed that for each 1% increase in SBM content, total gain improved by 0.51 lbs. and FCE improved by 0.0082 units. Diets ranged from 0% to 21% SBM with the highest SBM diet having an advantage of 10.4 lbs. whole-body gain and 0.18 FCE units over the no-SBM diet. However, the FCE improvement is underestimated in this study (fixed time, 37 d) because end weight was lower than for the highest SBM diet. If pigs fed the zero SBM diet (-10.4 lbs.) were allowed time to gain an equivalent weight, FCE would become worse (+0.0055 FCE units for each 1.0 lb. gain).

Growth Constrained by DDGS Suppression of Feed Intake

An important feature of maximizing growth involves choosing ingredients (type, amount) that do not decrease feed intake and ultimately growth. The growth-limiting effect of DDGS was illustrated in the study by van Heugten (2024), where diets with 25% DDGS reduced daily feed intake by 4.0%. This is a timely reminder that ingredient characterization cannot be limited to available nutrient content. Ingredients such as DDGS, canola meal, wheat midds and corn germ meal are good ingredients, but each suppresses feed intake at some dietary level and this differs by phase of growth (internal ingredient research studies at the Hanor Co. by Boyd, Rush, Rosero and Elsbernd).

In the van Heugten study (2024), inclusion of 25% DDGS reduced total live weight gain by -4.1 lbs. (regression estimate) compared to the C-S group (P=0.046). This difference is primarily due to a DDGS-induced reduction in feed intake (-0.31 lbs./d), but there is also an indirect effect of DDGS in that its presence reduced SBM content (3.1% to 3.3% less), which compromises growth. The latter could account for a loss of 1.58 to 1.68 lbs. of the 4.1 lbs. weight deficit, based on the regression relationship in **Figure 1** (-0.51 lbs. per 1.0% SBM). The negative effect of DDGS was greater when expressed on a carcass gain basis, because carcass yield was also compromised (73.04% vs 72.62%, SEM 0.27. P=0.034).

Pigs fed diets with DDGS did not differ from the C-S group in FCE (3.31 vs 3.28; P=0.425). When FCE is adjusted to an equivalent weight gain for DDGS-fed pigs (93.9 lbs.), the numerical 'difference' increased (3.33 vs 3.28; using 0.0055 FCE units/lb. of late-finishing gain).

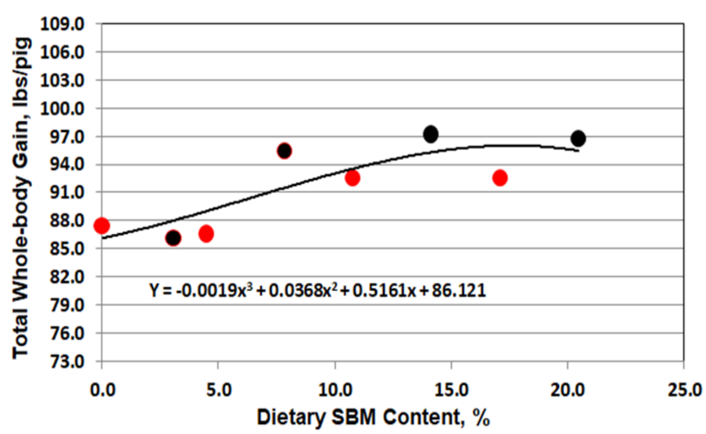
The deleterious effect of DDGS on feed intake has also been reported by Rosero and co-workers (2024). The level that can be fed without causing reduced feed intake is lowest for nursery pigs (25 to 50 lbs.). This suppressing effect of DDGS gradually decreases as pigs grow (e.g., 65 to 180 lbs.) with pigs in the mid- to late-finishing phases (>180 lbs. body weight) having a higher tolerance for dietary DDGS level (internal ingredient research by Hanor Co., cited above).

Estimating SBM Level for Maximum Growth

Estimating the dietary SBM level needed to maximize growth is similar to the 'dose-response' method that is used to define nutrient requirements. Growth response (total gain, FCE) to increasing increments of SBM is determined by increasing levels from near zero to a level that is expected to exceed the need for maximum response. The principle is shown in **Figure 3** by using the total gain data from **Figure 1**. A polynomial curve was used since it accounted for slightly more of the variation in response. The shape of the curve exhibits the expected biological response over the range of SBM increments that are low enough to be deficit and high enough to exceed the need for maximum growth.

The FCE response in **Figure 2** appears to be linear rather than nonlinear with an apparent plateau found in **Figure 3**. This suggests that a higher level of SBM is needed for maximum FCE expression. This 'disparity' is typical when using multiple criteria for a nutrient requirement assay (Lewis, 1992; Baker, 1997). The nutrient need for one function often differs from that needed for another. In many instances, the amino acid needed to support maximum gain is below that required for minimum FCE. In commercial practice, financial analysis is applied using the regression equations to predict value created, which is compared to the diet cost to deliver it.

Figure 3. Total whole-body gain in response to dietary SBM content (adapted from Figure 1).



Studies to Estimate SBM Content for Maximum Growth

Two of our commercial studies (Zier-Rush et al., 2014; Boyd et al., 2024b) were used to confirm the concept of SBM-mediated maximum growth and whether minimum estimates could be determined. Both studies were conducted in 2 buildings on sites (nursery, finish) housing up to 10,000 pigs (22–25 pigs/pen). Diet design for each study limited ingredient substitution to the exchange of SBM with corn and 4 amino acids. Fat level was adjusted to hold dietary net energy (NE) constant (SBM NE values, Boyd et al., 2023; NE values for other ingredients, NRC, 2012). The concept of SBM-mediated maximum growth expression was confirmed by both studies and this allowed us to derive minimum SBM estimates.

Data from our paper (Boyd et al, 2024b) covered weight gain from 65 to 295 lbs. We extended it backward to the final nursery phase (24 to 65 lbs.) by using data from the report by Zier-Rush and co-workers (2014). Diet design was similar for both studies (conducted in 2013, 2014 respectively).

Growth Response to Increasing Dietary SBM

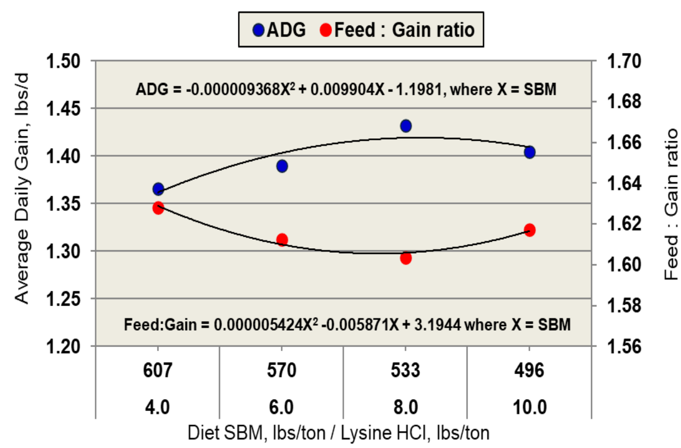
We observed 3 distinct response forms to increasing dietary SBM over the 24 to 295 lbs. interval. The response during the nursery period (24 to 65 lbs.) was U-shaped, which allowed us to determine the minimum or maximum for FCE and gain, respectively, by a straight-forward mathematical procedure. Two response forms were observed for the grow-finish (GF) period. The growing phase (65 to 145 lbs.) exhibited a gentle linear erosion in FCE at SBM levels below the minimum response. After 145 lbs. body weight, the erosion in FCE and growth rate with declining SBM content was more dramatic and quadratic in form. There was no indication of penalty to whole-body growth for GF phases as observed for the nursery period. Details for each growth phase are shown below.

<u>Nursery phase, 24 to 65 lbs.</u>

The data set that we used is presented in **Table 1**. Regression equations were derived from growth rate (lbs./d) and FCE responses to SBM content (**Figure 4**). The estimate that maximized response was determined separately for each criterion. Estimates were similar for maximum growth (527 lbs./ton) and minimum FCE (544 lbs.). Feeding diets with less SBM allowed performance to gently erode for both measures. To our surprise, feeding diets with greater SBM content than was needed for maximum growth or minimum FCE compromised both measures. Since the weaned pigs (weaning age, ~20 d) were still acclimating to diets with increasing amounts of SBM (>500 lbs./ton), we suspect that higher levels may have exceeded their digestive ability or altered the rate of digesta passage at this early stage of development.

We did not include data for diet 5 (12 lbs. L-lysine/ton) in **Figure 4** because the dietary valine level was marginal to slightly deficient valine (NRC, 2012).

Figure 4. Growth and FCE response to declining SBM content in late nursery pig diets. Study was fixed time, 29 d. Average initial weight 24 lbs. (Zier-Rush et al., 2014).



In commercial practice, the equations would be used to derive a financially based estimate for minimum dietary SBM level. In some cases, the financial optimum would be below the level needed to maximize growth or FCE if diet cost exceeded the value of weight created.

Table 1. Growth response of pigs to declining dietary SBM level in the last nursery phase (24 to 65 lbs)[1,2]

		Synthetic Lysine Dose						
Item	Unit	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5		
Diet Net Energy	mcal/kg	2.505	2.503	2.502	2.500	2.498	-	-
Diet SBM content	lbs/ton	607	570	533	496	459	-	-
Diet Lysine.HCl content	lbs/ton	4.0	6.0	8.0	10.0	12.0	SEM	Diet, P=
No. Pens	-	17	17	17	16	17	-	-
No. Pigs Placed	-	333	336	331	324	341	-	-
Days on test	days	29	29	29	29	29	-	-
Initial weight	lbs	23.8	23.8	23.8	23.9	23.7	0.6	1.0
Final weight	lbs	63.4	64.1	65.3	64.6	64.5	1.0	0.7
Daily gain	lbs/d	1.37	1.39	1.43	1.40	1.41	0.02	0.046
Daily feed intake	lbs/d	2.23	2.24	2.30	2.27	2.32	0.03	0.455
Feed : Gain ratio	lbs/lbs	1.63	1.61	1.60	1.62	1.65	0.01	0.002

[1] Data obtained from Zier-Rush et al., 2014; diet composition can be accessed using the DOI: http://dx.doi.org/10.13140/RG.2.2.23328.29449

[2] Phytase super-dose (e.g., 2500 FTU/kg) was not used to minimize adverse effects of increasing diet phytate on mucosa. Diets contained 600 FTU phytase/kg of diet (Danisco, Axtra® PHY).

GF phase, 65 to 270 lbs.

The data used to estimate the minimum SBM level for this period of growth was derived from our recent publication (Boyd et al., 2024b). The study involved increasing crystalline lysine (L-HCl) to determine the maximum level that could be used without compromising growth rate or FCE. In the process, SBM content decreased as dietary L-HCl increased. The dose-response curve for increasing SBM content on growth rate and FCE was created by reversing diet order. The similarity of the SBM response curve to that of a nutrient is nicely illustrated for pigs in early- (145 to 195 lbs., **Figure 5**) and late-finishing periods (195 to 270 lbs., **Figure 6**). A polynomial equation was developed for each criterion to describe the response and for financial modeling of the SBM level to optimize profit (i.e., value created minus diet cost invested).

Estimation of minimum SBM levels for the early GF phases (65 to 105 lbs. and 105 to 145 lbs.) presented a special challenge, because the response involved a gentle, linear departure from the control diet (highest SBM). This is illustrated for the 65 to 105 lbs. phase in **Figure 7**. In addition, the daily gain response for this phase seems counter-intuitive, because growth increased as SBM level declined (Linear, P=0.096) and this conflicts with the FCE response and growth response for later GF phases. However, these pigs steadily increased feed intake (Linear, P=0.001) as dietary SBM level declined below the maximum SBM control diet (**Figure 7**).

Figure 5. Daily gain and FCE response to increasing dietary SBM level (145 to 195 lbs. phase). SEM = 0.03 and 0.02, respectively. Means were derived from Table 6 of Boyd et al., 2024b.

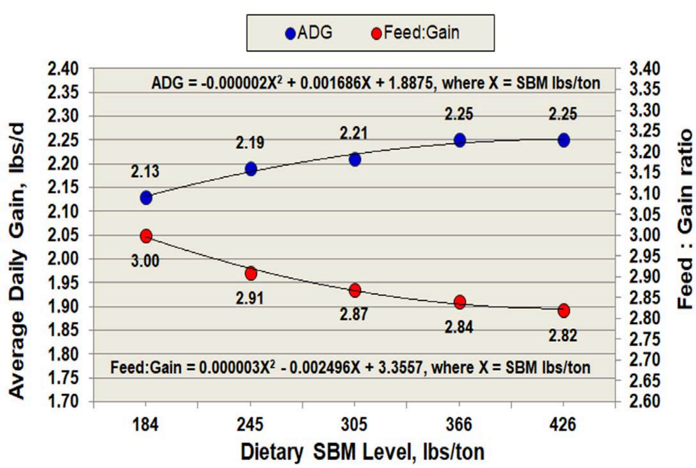


Figure 6. Daily gain and FCE response to increasing dietary SBM level (195 to 270 lbs. phase). SEM = 0.03 and 0.03, respectively. Means were derived from Table 7 of Boyd et al., 2024.

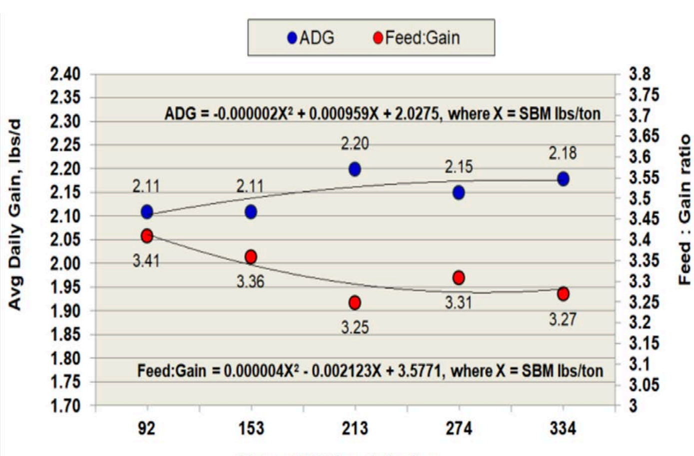
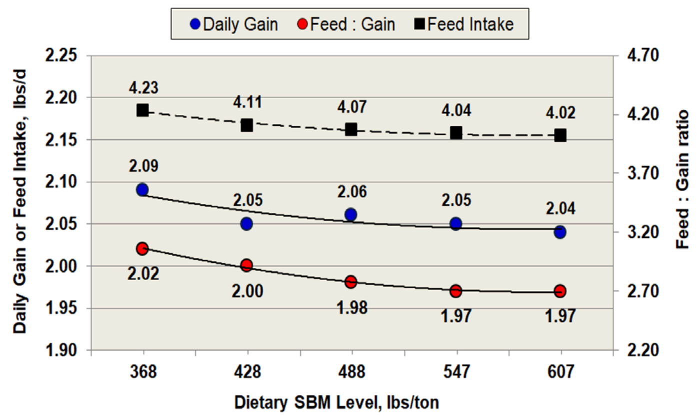


Figure 7. Feed intake, growth rate and FCE responses to increasing SBM in diets (65 to 105 lbs. phase). Means were taken from Table 4 of Boyd et al., 2024b. SEM for feed intake, growth rate and FCE were 0.05, 0.02 and 0.02, respectively. FCE = -0.0002X + 2.0940, where X = SBM lbs./ton.



The daily gain response is not uncommon for early stages (2–3 weeks) of an amino acid requirement test. It appears that pigs were over-eating, perhaps to correct for some dietary inadequacy, but this subsides after 2–3 weeks (Boyd et al., 2024b). Feed intake adjustment accounted for the increase in growth rate, but the composition of weight gained is presumed to contain more lipid since FCE was becoming worse (Krick et al., 1993).

GF phase extension, 270–295 lbs.

We extended our original analysis by attempting to utilize data from a 12 d period (270 to 295 lbs.) presented in the research report on which our 2024b paper was based (Zier-Rush et al., 2013); however, time on feed was brief and the data too variable to derive a trustworthy response curve to increasing SBM level. Instead, we used data from that report for the 245 to 295 lbs. interval, believing that increased experimental time (27 d) would provide a better estimate of responsiveness to SBM for the final finishing phase. This also had its limitations because 25% of the pigs were removed from each pen for harvest (normal practice). This disruption tended to increase variability in gain and FCE response above that observed in earlier phases (65 to 270 lbs.), where pen disruption was much less.

Nevertheless, we used the latter information to predict the effect of increasing dietary SBM content for the final phase with the result shown in **Table 2**.

Development of SBM Curve for Maximum Growth

Growth rate and FCE response to increasing dietary SBM content is described by regression equations that are provided in **Table 2**. Estimates of the minimum SBM level needed for maximum response for each criterion are shown for each of the 6 feeding phases. These estimates were assembled into a

Table 2. Information used to estimate dietary SBM minimum (lbs./ton) for maximum growth rate and FCE (feed:gain ratio) for 6 feeding phases

Growth Phase, lbs.	Max. Response [1]	SEM	Regression Descriptor ax^2	bx	c	SBM at [2] Max Response	Avg SBM [3] both Criteria
Feed:Gain	lbs/lbs					lbs.	lbs.
24 to 65	1.599	0.01	0.0000054	-0.005871	3.1944	544	535
65 to 105	1.979	0.02	-	-0.0002	2.0940	575	575
105 to 145	2.520	0.02	-	-0.0001	2.5685	482	482
145 to 195	2.837	0.02	0.0000030	-0.002496	3.3557	416	419
195 to 270	3.295	0.03	0.0000040	-0.002123	3.5771	265	253
245 to 295 [4]	3.981	0.07	0.0000064	-0.003552	4.4738	278	255
Avg Daily Gain	lbs/d					lbs.	
24 to 65	1.411	0.02	-0.0000094	0.009904	-1.1981	527	-
65 to 105	2.050	0.02	-	-	-	-	-
105 to 145	2.120	0.02	-	-	-	-	-
145 to 195	2.243	0.03	-0.0000020	0.001686	1.8875	422	-
195 to 270	2.142	0.03	-0.0000020	0.000959	2.0275	240	-
245 to 295 [4]	1.870	0.04	-0.0000050	0.002325	1.5998	233	-

[1] Represents the maximum response to SBM. The minimum SBM level (X) was determined as described in footnote 2 and inserted into the regression equation to compute the maximum response value shown.

[2] SBM content (X) to deliver the maximum response was estimated from the quadratic equation by finding its first derivative and solving for X (-b/2a). Pigs in the 65 to145 lbs. phase responded in a linear manner so defining the absolute minimum or maximum response was not feasible. Baseline or maximum response to SBM was defined as described in the text. The SBM level (X) to achieve the result (Y) was computed using the regression equation in the table above.

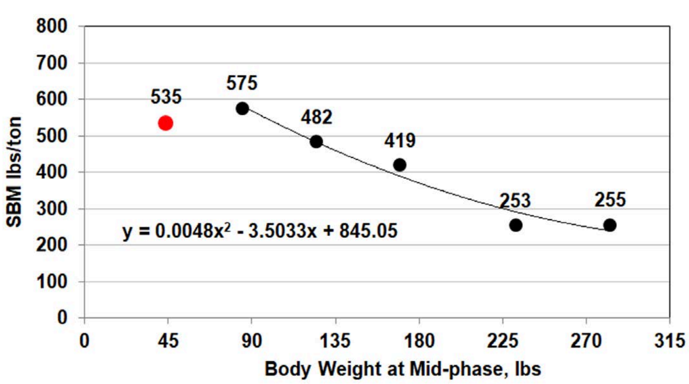
[3] These values are the mean of minimum SBM estimates for both criteria and are the best estimate of the minimum dietary SBM needed to maximize gain, and FCE response.

[4] This interval was estimated using response data for the 245 to 295 lbs. period (as described in the text), which was obtained from Zier-Rush et al., 2013; Table 2b.

minimum SBM content curve (24 to 295 lbs. live weight, **Figure 8**). It is provided as the basis for setting dietary constraints for SBM, when maximum growth rate is at a premium.

The minimum dietary SBM to deliver maximum growth or minimum FCE was estimated for quadratic equations ($aX^2 + bX + c$) by taking the first derivative of the equation and solving for X (-b/2a). This is the least amount of SBM for maximum expression of responses (**Table 2**.).

Figure 8. Minimum dietary SBM curve needed to maximize FCE and growth response.The curve was assembled from estimates in Table 2, the 24 to 295 lbs. period, and is based on SBM content needed to achieve best FCE. Body weights on the X-axis are mid-points for each phase tested.



Deriving the minimum SBM estimate for maximum growth responses over the 65 to 145 lbs. phase was more challenging, because the response was linear (**Table 2**). We defined the maximum response to be the average of means whose difference did not exceed ½ of the SEM. For example, FCE response for the 65 to 105 lbs. phase was computed from the regression equation, which resulted in the following 'best' estimate of response means: 2.020, 2.008, 1.997, 1.985 and 1.973 for 5 diets with increasing levels of SBM. Since the SEM was 0.02 FCE units, the estimate for maximum response was limited to the average of 1.973 and 1.985 (1.979). The minimum SBM level to achieve 1.979 was computed by solving the equation for the 'required' X. The minimum FCE response was 575 lbs./ton.

Estimates of the minimum dietary SBM level for each growth phase were used to assemble a curve (**Figure 8**) to guide nutritionists in setting dietary SBM constraints for maximum growth. The equation facilitates conversion of the curve to various feeding phases.

The minimum dietary SBM curve is appropriate for relatively healthy pigs (absence of clinical lesions of disease) that are reared under commercial conditions of high density population on the site and in pens (e.g., 4800 pigs or more; minimum of 22–25 pigs/pen). The SBM level for SRD-challenged pigs is expected to be much higher and related to the degree of

Table 3. Example application of the minimum SBM curve to derive the minimum level (lbs./ton) for two-phase feeding programs. Pig weights are lbs./pig[1]

Diet	8 Phase Diet Program				6 Phase Diet Program			
Phase	Start	End	Mid-Point	Min. SBM	Start	End	Mid-Point	Min. SBM
Nursery 3	25	50	38	535	25	60	43	535
Finish 1	50	90	70	623	60	90	75	609
Finish 2	90	120	105	530	90	130	110	518
Finish 3	120	150	135	460	130	180	155	417
Finish 4	150	180	165	398	180	230	205	329
Finish 5	180	210	195	344	230	295	263	256
Finish 6	210	240	225	300				
Finish 7	240	295	268	251				

[1] Minimum SBM is predicted by multiplying average pig weight at mid-phase by the equation from Figure 8 (Y, SBM lbs./ton = $0.0048X^2 - 3.5033X + 845.05$, where X = mid-phase weight. Using beginning weight for a feeding phase provides a margin of safety toward maximum response.

Table 4. Whole-body and carcass growth of pigs fed diets with declining SBM content (Diet 1 to 5) from 65 to 295 lbs.[1,2]

Criterion	Units	Control Dose 1	Dose 2	Dose 3	Dose 4	Dose 5	5 + BCAA Diet 6	SEM	Linear 1-5 Prob. P=	Diet 5 vs 6 Prob. P=
No. Pens	-	18	16	16	16	16	18	-	-	-
No. Pigs Placed	-	399	354	357	357	357	397	-	-	-
Average Days Fed	days	109.1	108.9	108.3	108.4	109.0	108.7	0.4	0.622	0.479
Whole-body Growth										
Total Gain	lbs/pig	295.2	293.8	295.9	291.7	290.7	291.0	1.8	0.043	0.890
Feed Efficiency	F:G ratio	2.91	2.93	2.93	2.99	3.05	2.98	0.02	<0.001	0.006
Carcass Growth										
End Weight	lbs/pig	218.3	218.3	219	216.9	216.4	215.8	1.5	0.259	0.801
Carcass Yield	%	74.1	74.2	73.9	74.2	74.3	74.2	0.19	0.238	0.719
Feed Efficiency	F:G ratio	3.91	3.83	3.91	3.96	4.03	3.98	0.02	<0.001	0.096
Carcass Lean										
FOM Loin Depth	mm	61.2	61.3	61.1	61.1	60.3	59.8	0.38	0.101	0.392
FOM Fat Depth	mm	21.9	22.0	22.1	22.4	22.4	22.3	0.24	0.035	0.741
FOM Lean Content	%	51.8	51.8	51.7	51.6	51.5	51.4	0.11	0.018	0.763

[1] Data derived from Tables 3 and 4 of Zier-Rush et al., 2014. Diet 1 has the highest SBM content with the level declining from Diets 2 to 5,; the latter having the lowest SBM level.
[2] Diet composition and nutrient content for Diets 1–6 are provided in Boyd et al., 2024.

respiratory challenge (Boyd et al., 2023). The SBM curve in **Figure 8** is expected to be less than what would be needed for pigs under SRD stress, but it is a good place to start when maximum growth is required (e.g., spring through summer).

Application of SBM Curve to Various Feeding Phases

The equation in **Figure 8** allows us to compute the minimum dietary SBM content specific to the number of feeding phases used by the production system (e.g., 4, 6, 8). This is illustrated in **Table 3**, where minimum dietary SBM content is shown for two feeding programs (complex or simple). The latter supports feed milling efficiency, which becomes important when feed demand is at or near mill capacity for manufacture.

SBM Deficit Constrains GF Pig Performance

The internal research report by Zier-Rush and co-workers (2013) had another important dimension to the study of dietary SBM content. They reported the effect of feeding the 5-SBM dose levels over a finish lifetime (placement to harvest; 65 to 295 lbs. live weight). To reiterate, this test was conducted on a commercial site that housed up to 10,000 pigs with 2 of the 8 barns retro-fitted for collection of research data.

The consequence of feeding diets with SBM levels below that needed for maximum growth and FCE for the entire GF period to harvest is shown in **Table 4**. Key performance outcomes would be used in a financial analysis to compare diet cost against the carcass value created. Business sustainability is greatest for systems that make decisions based on maximum profit. The latter are willing to increase input cost to create additional value for greater profit.

Pigs fed SBM levels below that needed for maximum growth (diet formats 4, 5) suggest a potential loss in profit opportunity. Although diet formats 4 and 5 were the least expensive diets, less saleable meat was produced (carcass lbs.) and more feed was required to produce the gain that was achieved (see carcass FCE). It is important to note that the level of SBM used in this study was not high enough to compromise carcass yield. This is a possibility with relatively higher dietary SBM levels. This little known principle is illustrated in the next and final chapter of this series.

Table 5. Illustration of setting minimum dietary SBM specification and ingredient nutrient specifications that includes SBM-equivalent content[1]

		Diet Specifications		Ingredient Specifications						
Nutrient or Class	Unit	Min.	Max	Corn 7.5	SBM 47.0	SBM 46.0	DDGS	MIDDS	L-Lysine	SBM Prmx
Net Energy	Mcal/lb	1.096		1.177	1.177	1.177	0.977	1.033	1.589	0.978
Total Crude Protein	%			7.5	47.0	46.3	27.4	16.5	92.6	22.4
SID Lysine : SID Protein	ratio		7.45	3.1	6.48	6.36	2.32	0.51	78.8	4.8
SID Lysine : NE	g/mcal NE	5.38		0.71	10.33	9.98	2.60	2.24	225.01	4.45
SID Lysine	%	1.30		0.18	2.68	2.59	0.56	0.51	78.8	0.96
STTD Ca	%	0.44		0.01	0.01	0.20	0.02	0.06	0.00	0.11
STTD P	%	0.32		0.09	0.09	0.09	0.33	0.16	0.00	0.14
Lactose	%	7.00		0	0	0	0	0	0.00	0.00
Lactose Equivalent Sugars	%	14.00		0	0	0	0	0	0.00	0.00
SBM Equivalents	%	28.0		0.0	100.0	100.0	0.0	0.0	0.0	35.0

1 SBM net energy (NE) is about 82%–83% of corn NE. The value shown is productive energy (PE), which has been shown to be a better predictor of SBM energy value in the commercial environment. PE encompasses classic NE plus conservation of total diet NE, as discussed by Boyd and Gaines, 2023.

Diet 6 was included to minimize the possibility that impaired growth was due to deficit of essential amino acids noted in our prior paper (Boyd and co-workers, 2024). Diet 6 corrected for the presumed isoleucine and (or) valine deficits of diet 5, and perhaps diet 4 (marginal). These 2 amino acids (branch-chain amino acids, BCAA) were added to a diet 5 equivalent to create diet 6 to meet or exceed their minimum requirement (NRC, 2012). This did not improve carcass growth or lean content, and less than 50% of carcass FCE that was lost with diet 5 was reclaimed by feeding diet 6. We proposed that growth was impaired by a limitation of SBM and not any of the 10 essential amino acids (Boyd et al. 2024a).

This concept of growth being compromised with typical levels of dietary SBM is supported by results from a recent field trial with the nutrition team (Dr. Trey Kellner) of the Audubon Manning Veterinary Clinic. The test involved approximately 104,000 pigs (extremely healthy) with a growth rate and FCE advantage produced by diets that contained more SBM. The results and financial evaluation are presented in the final article in this Feedstuffs series.

Formulating to a SBM Specification

Delivering on diet specifications for SBM (**Figure 8**) requires setting a minimum SBM constraint for each diet phase. SBM is inserted into the nutrient requirements column for diets (**Table 5**). This enables setting a minimum constraint for SBM content, which can only be met by SBM ingredients, or those that contain some SBM. Each SBM ingredient (e.g., 44% to 49% CP) has its SBM equivalence loading set equal to 100 (as-is basis) in the nutrient content column. A base-mix that contains 35% SBM has its SBM equivalence set to 35. Corn, DDGS and all other ingredients, including other protein ingredients (e.g., high CP DDGS, corn germ meal, and canola meal), have their SBM equivalent content set to zero.

If the minimum SBM specification for a diet is 366 lbs./ton of feed, the SBM constraint in the dietary nutrient specification side is set to 18.6% (**Table 5**). This is satisfied with 18.6% SBM, whether the source is 45.4% or 48.3% CP SBM. No maximum diet constraint is needed because SBM price normally becomes a self-limiting factor. The exception is for nursery diets where maximum SBM content is set to prevent excessive SBM exposure as the weaned pig makes a transition to C-S diets. These concepts are shown in **Table 5**, where the SBM equivalent 'requirement' is shown under diet specifications (blue section). Ingredients available to the formula show SBM equivalent content in the nutrient level column (gray section).

This approach to specifying dietary constraints for an ingredient type (under nutrient specifications column) is routine in commercial feed formulation. Dr. Gary Stoner (Sr. VP emeritus, CP Group – China) recognized the importance of a minimum dietary SBM level for both poultry and pigs more than a decade ago (personal communication, June 2025). He set minimum SBM equivalent specifications for diets to avoid growth and FCE erosion that inevitably occurred when dietary SBM content was 'too' low.

Their challenge was how to value alternative soybean products whose composition had been altered. The SBM-equivalent specification for high-oil-containing soybeans (e.g., 23% oil) might be reduced by the oil content above that for 'typical' SBM. Equivalence for full-fat soybeans would be reduced as follows: 100 – [23-2.5]=79.5. Another example is a product that has been enzymatically treated to remove carbohydrate components that are antagonistic to weaned pig mucosa integrity. It could be listed as containing 100% SBM equivalence, provided that the content of functional compounds was not altered in the process.

There is no basis to discriminate among SBM CP levels at this time since we do not know what portion of SBM confers the ability for improved growth or resilience to respiratory disease. We do know that isoflavones and saponins mitigate the effects of SRD infection (Smith and Dilger, 2018; Smith et al., 2020).

Formulation to SBM Specification – Indirect Measures Not Specific

The question of whether an indirect measure can be used to specify a minimum level of SBM has been raised in conversations with other, especially young, nutritionists.

Figure 9. Pattern of a potential formulation measure (SID Lysine:total CP ratio) resulting from a specific minimum dietary SBM content. SBM levels in the figure below represent an early, theoretical minimum SBM curve.Ingredients included in formulations include: SBM, DDGS, 4 amino acids.

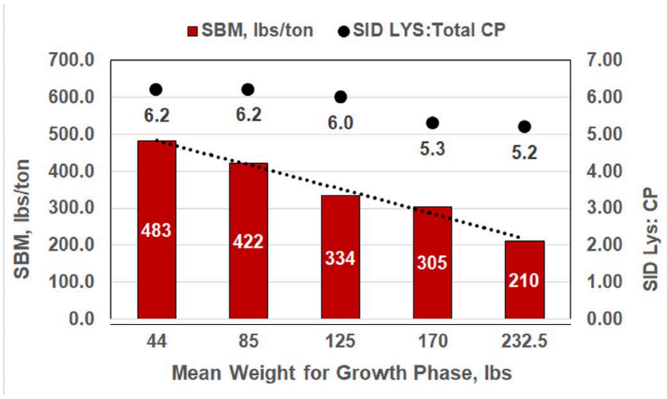
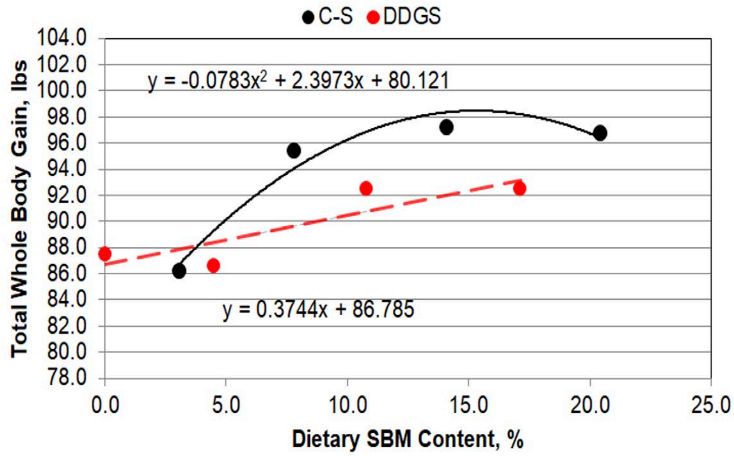


Figure 10. Total gain response to increasing dietary SBM content with or without DDGS. Figure developed using data from Figure 1.



We use the term indirect in the context of a measure that is intended to specifically relate to the dietary target, SBM. This question is raised because many are not aware of the direct, specific procedure that is described above. The direct approach is common for the commercial feed sector (esp., European). Setting diets and ingredients for SBM-equivalence is also being done by several in the commercial pork sector.

In response to questions about an indirect formulation measure (e.g., standardized ileal digestible (SID) Lysine:CP ratio) to achieve a specific level of dietary SBM, the senior author has provided an illustration of what this could look like if SID lysine:total CP ratio was the measure used (**Figure 9**). The problem with this term, and other variants (minimum CP level, SID Lysine:SID CP ratio) is that total dietary CP level is not limited to SBM CP. Protein from other ingredients would be included in the CP mass (e.g., DDGS, corn germ meal, wheat, barley). For that reason, skilled commercial nutrition formulators, such as Dr. Stoner, use the SBM term since it is specific to the dietary target, SBM.

Growth is suppressed by Typical Dietary DDGS Levels

The principles for maximizing growth rate are broader than providing the proper level of dietary SBM. There appears to be a conflict between maximizing weight gain with SBM and the presence of DDGS in the diet (e.g., >10%). This possibility originated with a closer look at the work by van Heugten (2024). In his study, total gain was measured for pigs fed a C-S diet or a C-S diet with 25% DDGS. Total gain increased in a linear manner as dietary SBM level increased (**Figure 1**). One regression line was plotted because the test for an interaction of diet format (±DDGS) x L-lysine level (0, 4, 8, 12 lbs.) resulted in a probability = 0.167. Nevertheless, we replotted the data separately for each diet type (**Figure 10**), on the basis that the sensitivity of test may have been limited by the number of experimental units.

The revised plot (**Figure 10**) shows that at the same dietary SBM level (10% or more), DDGS-fed pigs weighed 4–5 lbs. less than those fed diets without DDGS. The DDGS-induced reduction in feed intake (-0.31 lbs./d) accounts for some of the difference, but not all of it. One could have provided a diet with the specified minimum SBM level for maximum growth rate, but not achieve it. It is not clear whether there is a practical level of SBM that could overcome the growth limiting effect of DDGS.

Commercial Research Confirms Growth Suppression by DDGS

Elsbernd and co-workers (2022) conducted a study in a field research site to determine the growth response of pigs fed diets with increasing SBM content. They confirmed that pigs fed a diet with a moderate level of DDGS did not grow as rapidly as those fed a C-S diet, even though both diets had the same level of SBM. In other words, the same dietary SBM level was associated with different growth rates, depending on whether DDGS were present. This agrees with the proposition that maximum gain cannot be achieved by the addition of a DDGS level typical for 'practical' commercial diets.

Their study was conducted on a 4800 GF pig site with 2 barns retrofitted for research. Approximately 2280 pigs were used in a growth trial to harvest. Pigs were placed in 96 mixed-sex pens (23–25 pigs/pen) and allocated to 4 dietary treatments: 3 SBM levels (low, medium, high) and a reference diet that has been typical for commercial practice (C-S, 20% DDGS). The SBM content of the reference and low SBM diets was equivalent and this comparison exposed the suppressing effect of DDGS on growth. The response to SBM level and DDGS use is shown for the 2 growth phases since the growth-impairing effect of DDGS tends to be more profound early in the GF period (Elsbernd et al., 2022).

The treatment framework is shown in **Table 6**. This design allowed them to study the effect of SBM level and to determine if a moderate level of DDGS conflicts with the objective of maximum growth. The publication by Elsbernd et al. (2022) is accompanied by the meeting slides to provide greater detail.

The reference diet listed in **Table 7** not only contained DDGS

Table 6. Framework for the study of dietary SBM level and growth expression[1]

Treatment	DDGS Level, %	Growth Phase lbs. 88 to 130	130 to 189	189 to 229	229 to 291
Practical Ref	20	19.0	14.0	9.5	7.5
SBM Low	0	19.0	14.0	9.5	7.5
SBM Med	0	24.5	18.0	13.0	10.5
SBM High	0	30.0	22.0	16.5	13.5

[1] Soybean meal (SBM) diets consisted of corn, SBM and amino acids.

Table 7. Growth rate of pigs (88 to 183 lbs.) to dietary SBM level with or without DDGS[1,2]

Item		Dietary Treatments REF	SBM Low	SBM Med	SBM High		
No. Pens		24	24	24	24		Probability
No. Pigs		567	571	573	572	SEM	DIF =
0 to 21 d							
Diet NE	Mcal/lb	1.162	1.123	1.124	1.125	-	-
Daily gain	lbs./day	1.95	2.01	2.03	2.05	0.022	0.015
21 to 42 d							
Diet NE	Mcal/lb	1.171	1.148	1.150	1.149	-	-
Daily gain	lbs./day	1.95	2.02	2.05	2.00	0.024	0.032
0 to 42 d							
Calc. gain	lbs./pig	81.8	84.6	85.6	85.5	-	-

(20%), but also contained added fat (3.0%) to replicate a heat stress diet format. This accounts for the slightly greater caloric content (NE) than for SBM diets (no added fat). The study was conducted during the summer months, with moderate heat stress (northern Iowa), which explains the fat addition to the reference diet. Despite the caloric advantage, the presence of a moderate level of DDGS impaired growth, which resulted in an inferior total gain of nearly 3.0 lbs. body weight for the 42 d growing period. There was also an advantage in total gain for using a higher (medium) SBM level.

We conclude that there is a conflict between maximizing weight gain with SBM and the presence of DDGS in the diet (>10%). If growth is at a premium, then DDGS cannot be used at typical dietary levels beyond a level that may support gut health without compromising growth rate (e.g., 5% to 8%). This is in agreement with 2 studies involving early and late GF pigs (Giacomini et al., 2025). Treatment design resembled van Heugten's framework (2024) with 4 SBM levels on 2 DDGS levels, but pigs were reared under commercial conditions (4080 pigs, 34 pigs/pen). In both phases, feeding DDGS suppressed growth rate (SBM x DDGS, P=0.088 and P=0.033 respectively).

Variation for Minimum SBM Estimates are Expected?

Our paper presents estimates for the minimum dietary SBM level to achieve maximum FCE and growth of pigs in the commercial environment. Pigs were derived from sow farms that were PRRSv and mycoplasma pneumonia positive, but clinically stable. There were no clinical signs of disease observed during the test. The estimates represent a starting point for a healthy pig flow; however, they are expected to be insufficient during respiratory disease stress, which causes extreme growth and FCE suppression (Boyd et al., 2023).

Boyd and co-workers (2023) provided an illustration of how an active respiratory infection can dramatically increase the amount of SBM needed to mitigate growth suppression. Pigs in the 217 to 260 lbs. phase (mid-point, 238 lbs.) needed at least 28.6% SBM to prevent impaired growth. This stands in stark contrast to the amount determined for the clinically healthy pigs described in this paper – 14.1% SBM (computed from equation in **Figure 8**). Although the studies were not cohorts in time, the SBM level to maximize growth of clinically healthy pigs was only 50% of the need for an active SRD infection (Boyd et al., 2023). This emphasizes the need to carefully document the health status of pigs being studied.

Seasonal Variation

Finally, season is expected to be a notable cause of variation in the amount of dietary SBM needed to maximize growth and FCE (winter vs summer); the issue being whether barns are closed to preserve warmth or open to extensive airflow. While pigs may not show clinical signs of disease, the influence of environmental factors cannot be ignored for their ability to induce inflammatory responses, in general (Roque et al., 2018). Noxious gases can impair tissue barriers to pathogens and pathogen particles (e.g., lipopolysaccharide) are transported on dust particles to illicit inflammation response (Knetter, 2013). These are a special concern during the winter and early spring months since they concentrate in the air when barns are closed to keep the pigs warm. This challenge to system health may be sustained over a longer time period than SRD challenges that persist for 2–4 week intervals (Boyd et al., 2023).

SRD disease pathogens are probably always present in commercial settings, but they are more likely to become a problem when room air flow is restricted, thereby increasing the concentration pathogens and noxious particles compared to late spring and summer (personal communication, Dr. Paul Yeske in April 2023). It is possible that these environmental components may impose immune stress and be countered by SBM to result in better growth and perhaps improved total diet NE use for growth (Boyd and Gaines, 2024).

Conclusions

Our paper confirmed the original concept of a minimum amount of dietary SBM needed to maximize growth and FCE. This is a new concept for improving the expression of genetic capacity for growth in pigs. We also showed that the facilitating effect of SBM on growth could be undermined by the use of typical DDGS levels.

1. Maximum growth and FCE in the commercial setting is positively associated with dietary SBM level.
2. A minimum SBM level is needed to maximize the expression of genetic capacity for growth in pigs.
3. Minimum dietary SBM curve was developed for maximum growth, FCE and carcass lean of high-health pigs at all feeding stages from 24 to 295 lbs.
4. Feeding diets with DDGS (e.g., 15%–25%) undermines the ability of SBM to maximize growth. When growth is at a premium then dietary DDGS should be kept to <10%.

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