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Analysis of Economically Optimal Nutrition and Marketing Strategies for Paylean® Usage in Hog Production

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An approach to the development of the economically optimal dietary concentration of Paylean, duration of the Paylean feeding, and dietary lysine concentration for finishing hog production is presented. A simulation model describing daily growth of hogs under different Paylean and lysine concentration combinations was adapted for optimizing nutrition and marketing when feed is supplemented with Paylean. Net returns per pig space per day under four alternative payment schemes are maximized based on 10-year average price levels and production costs. Profitability of Paylean is investigated, and management strategies for swine production with Paylean are developed for two representative finishing operations.

Key words: Paylean®, ractopamine, swine production

Introduction

Paylean® is the brand name of the swine feed additive ractopamine marketed by Elanco Animal Health. Paylean® was approved by the U.S. Food and Drug Administration (FDA) in late 1999 for use in the swine industry. Research has shown that the additive can increase lean growth rates and feed efficiency, with concurrent changes in body weight growth rates, feed intake, and dressing percentage (Anderson et al.; Moody, Hancock, and Anderson; Watkins et al.). Hence, this feed additive is a potentially profitable tool for adoption by producers to raise leaner hogs while using less feed.

The adoption of Paylean in hog production is complex, however, because growth response is determined not only by the Paylean concentration and duration of feeding, but also is affected by many other factors, such as nutrition, the growth environment, and genetics. Dietary protein concentrations must be adjusted simultaneously with Paylean concentration to obtain the maximum lean growth response. Economically optimal management of both Paylean concentration and dietary protein is determined by the values paid for finished hogs, especially for lean meat, as well as the costs of feed and Paylean. With so many variables—weight to begin Paylean supplementation, dietary protein level, genetics, environment, etc.—the cost of on-farm experimentation to determine the optimal Paylean concentration is prohibitive.

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To determine optimal management strategies for Paylean, nutrition, and marketing, a simulation model is developed which combines a biological growth model and an economic model. The biological growth model simulates the growth of pigs through the accretion of the principal chemical components of the empty body (i.e., live weight less intestinal contents). These components are protein, lipid, water, and ash (Whittemore and Fawcett; Bridges et al.; Schinckel et al. 2002), with protein and lipid representing the two primary components. The biological growth model is designed to incorporate the level of dietary protein and the concentration of Paylean in the feed as model inputs, with growth responding to these levels (see Schinckel; Schinckel et al. 2003).

The economic model builds upon the optimal replacement problem in a livestock setting (Burt 1963, 1993; Chavas, Kliebenstein, and Crenshaw; Boland, Preckel, and Schinckel). One important aspect of the problem, discounting for carcass quality, has either been ignored in most previous work, or addressed in only a cursory manner. In the hog industry, a discount for hogs outside the packer's ideal weight range and carcass leanness may be assessed. Discounts shift the price paid per pound for hogs, and the discount increases in discrete steps as the carcass weight (or carcass quality) deviates further from the ideal range.

Earlier studies have either failed to consider discounts or have used smooth approximations to them. The exception is the work of Millar et al. (1990b) who showed that the discrete steps in the discount schedule can have a strong influence on the optimal marketing weight. Because these discounts are step functions, they render the objective function discontinuous, and thus nonconcave. Hence, the optimum may not satisfy the standard Karush-Kuhn-Tucker optimality conditions which depend fundamentally on differentiability of the problem objective and constraints. Likewise, the optimization cannot be achieved via standard numerical optimization methods which focus on finding a solution to the first-order conditions for the problem. Therefore, the optimal values for management variables are identified in this research via a grid search.

The study examines management strategies for nutrition and marketing when feed is supplemented with Paylean, which is a relatively new technology currently undergoing rapid adoption by producers in the United States and worldwide. The biological model simulates the growth of body weight and body components, mainly lean and fat tissues. The model is general in the sense that it can be calibrated to genetic and environmental conditions specific to the farm for which management recommendations are to be developed. The model reflects changes in component growth due to restriction of lysine below the level needed for maximum protein accretion of the animal. While the maximum protein accretion curve of pigs is usually determined by the genetic lean growth capacity, feeding pigs with Paylean shifts energy intake away from lipid accretion and toward protein deposition, and shifts the maximum protein accretion curve upward. Interested readers are referred to Schinckel et al. (2003) for specific details on the biological growth model including the Paylean effects.

This research seeks to extend previous economic analyses on ractopamine usage in hog production—mainly the feasibility studies of the product conducted in the early 1990s (e.g., Millar et al. 1990a, b; Kitts et al.). Here, the Paylean concentration and lysine level in the feed are optimized from an economic perspective. Thus, a second goal of this study is to provide updated estimates of the profitability of Paylean reflecting the genetic improvements in lean growth in recent decades, which have altered pig growth responses to Paylean.

Simulation Model

The biological model (Schinckel et al. 2003) is modified by the addition of calculations of an objective function to be maximized. In line with previous work on the livestock replacement problem, the objective is average return (revenue less variable costs) per pig space per day, which implicitly assumes a continuous production process where farmers have feeder pigs ready to replace the finishers and refill the facility.[1] Thus, the model accounts for the opportunity cost of facilities.[2]

The objective function value is calculated for each of the alternative combinations of values for lysine level, Paylean concentration, time to initiate Paylean supplementation, switching time between diets for the phase feeding program, and marketing time. The model searches over small steps within specified ranges for each of these variables in order to determine the combination of variable levels yielding the approximate optimum.

The range and step size for lysine concentration are [0.5%, 1.3%] and 0.01% (lysine concentration is measured as a percentage of the feed by weight), and those for Paylean concentration[3] are [3 ppm, 20 ppm] and 0.5 ppm. Using these ranges, the optimal lysine level was strictly interior to the specified range for all calculations reported. Because the simulation model is based on a daily time period, the initiation time for Paylean supplementation, the switching time between diets, and the marketing day for finished hogs are optimized to the nearest whole day. Paylean feeding duration is optimized over days ranging from the day when the hog reaches 150 pounds onward, with the restriction that the maximum weight gain on Paylean cannot exceed 90 pounds.

The designs of the ranges for Paylean concentration and for the time of initiation of Paylean supplementation and the maximum weight gain on Paylean reflect restrictions currently imposed by the FDA. In the United States, Paylean supplementation is only permitted for hogs between 150 and 240 pounds, implying total weight gain on Paylean cannot exceed 90 pounds. Consequently, the model restricts the starting weight on Paylean to be greater than 150 pounds, and weight gain on Paylean to be less than 90 pounds. However, the model optimizes the marketing day without regard to the upper weight limit of 240 pounds. The market weight is the highest weight on Paylean (if supplemented) because it is not economically optimal to withdraw Paylean from the diet (or to reduce its concentration level) for any extended period as the growth rate will drop sharply.

There are two reasons for not limiting the market weight. First, there are no regulations for maximum weight on Paylean in countries other than the United States, and second, even in the United States, the regulated upper limit is expected to rise in the near future. The ractopamine concentration allowed in the model is also broadened from the FDA's legal range of 5–20 ppm to 3–20 ppm, considering application outside the United States. Therefore, this research allows for a somewhat broader scope than that currently permitted in the United States.

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[1] A model which maximizes return per pig implicitly assumes the pig facility is to be used for one time only, and no other pigs are to fill the facility once the current group is marketed. Maximizing return per pig space per day takes into account the replacement of the current group of finishers with a new group of feeder pigs.

[2] The time value of money is not accounted for in this study, because the time span from feeder to finisher is typically around three months and interest rates are low in the United States. Hence it is not critical to discount the returns and costs over time. However, the model can be adapted easily to include discounting. The model does consider the opportunity cost of the space occupied by an older animal that could be replaced by a younger, faster-growing animal.

[3] In this article, the term "concentration" indicates the dosage level of Paylean in the swine diet. The dietary concentration of Paylean is in units of parts per million (ppm). A concentration of 5 ppm corresponds to 4.5 grams of Paylean per short ton of feed.

Data

For purposes of demonstration, the model is applied to the analysis of management strategies for modern genotypes under two sets of production conditions. The two growth environments examined are: (*a*) a modern facility and production system characterized by segregated early weaning (SEW) and all-in/all-out (AIAO) technology (hereafter referred to as the SEW farm); and (*b*) an older, continuous-flow (CF) facility characterized by persistent health problems and a lower average growth rate.[4] The two environments represent above- and below-average management levels and hog growing conditions. Without Paylean, gilts and barrows raised in the SEW environment have higher average lean growth rates and better feed efficiency than CF pigs (Kendall et al.). Gilts and barrows are modeled separately because their growth rates, carcass compositions, and feed intakes differ.

The model is designed as a farm-level model, where prices of feed, feeder pigs, finishing hogs, and Paylean are taken as given to producers. Ten-year average prices from 1991 to 2000 are used to ensure relative prices of important inputs and outputs are approximately in equilibrium. (This ignores any changes in relative prices due to widespread adoption of Paylean.) Price summaries are reported in table 1, where standard deviations of these historical prices are used for sensitivity analysis, and the price of Paylean is set at \$2.25 per gram, the market price in 2002.

Data on live hog, corn, and soybean meal prices are from U.S. Department of Agriculture (USDA) statistics. Feeder pig prices are obtained from the statistics listed in "Estimated Livestock Returns," tabulated by the Iowa State University Cooperative Extension Service (Lawrence). Also from "Estimated Livestock Returns," two categories of variable production costs are used in the model—the transportation cost of \$2/head, and a daily variable cost of 9¢/head/day covering labor, utilities, veterinary services and medicine, and miscellaneous expenses.

Four payment schemes spanning the range of pork industry practices are modeled. The differences between these schemes are well defined by the payments hog producers receive for lean meat relative to fat tissue and the discount/premium schedules. The four payment schemes are described as follows:

- SCHEME 1. Producers are paid for carcass weight (and so lean and fat are valued equally), with discounts on under-weight and over-weight carcasses. The discount grids are given in table 2.
- SCHEME 2. Producers are paid for carcass weight, with discounts for fatness and premiums for leanness based on the lean percentage estimated from muscle and fat depth. Discount and premium grids are given in table 3.
- SCHEME 3. Producers are paid separately for lean and fat, with the lean-to-fat price ratio set at 2:1.
- SCHEME 4. Producers are paid separately for lean and fat, with the lean-to-fat price ratio set at 4:1.

[4] The segregated early weaning protocol involves weaning pigs at less than 18 days of age while colostral antibodies still protect them from many diseases that are endemic in the sow herd. These pigs are then segregated into a separate ventilated airspace usually located on a different site. Pigs are never commingled with those of other ages or from other farrowing sites. All-in/all-out (AIAO) refers to the lack of commingling—i.e., new pigs do not enter until all the previous pigs have left and the space has been properly cleaned.

Table 1. Summary of Ten-Year Average Prices for Key Inputs and Output (1991–2000)

	Commodity			
Description	Corn ($/bushel)	Soybean Meal[a] ($/ton)	Feeder Pigs ($/head)	Live Hogs ($/cwt)
10-Year Average	2.32	191.03	42.00	43.00
Standard Deviation	0.44	37.82	8.93	7.30
Minimum	1.82	138.50	30.66	30.30
Maximum	3.24	270.90	58.05	52.90

Sources: Corn and hog prices are from USDA/National Agricultural Statistics Service (NASS); soybean meal prices are from USDA/Agricultural Marketing Service (AMS); feeder pig and live hog prices are from "Estimated Livestock Returns," tabulated by the Iowa State University Cooperative Extension Service (Lawrence).
[a] The specific price is for 48% crude protein soybean meal quoted at Decatur, Illinois.

Table 2. Carcass Weight Discount Grids for Under- and Over-weight Hogs Programmed for All Payment Schemes

Estimated Live Weight Range (pounds)	Hot Carcass Weight Range (pounds)	Discount for Payment Schemes 1 and 2 ($/cwt of scalded carcass)	Discount for Payment Scheme 3 ($/cwt of lean)[a]	Discount for Payment Scheme 4 ($/cwt of lean)[b]
Under 190	Under 140	-9.46	-14.33	-16.31
191–200	141–148	-9.46	-14.33	-16.31
201–210	149–155	-6.76	-10.24	-11.65
211–220	156–163	-4.05	-6.14	-6.98
221–229	164–169	-1.35	-2.05	-2.33
230–240	170–177	0.00	0.00	0.00
241–250	178–185	0.00	0.00	0.00
251–260	186–192	0.00	0.00	0.00
261–270	193–200	0.00	0.00	0.00
271–280	201–207	0.00	0.00	0.00
281–290	208–214	-0.68	-1.03	-1.17
291–300	215–222	-2.03	-3.08	-3.50
301–310	223–229	-3.38	-5.12	-5.83
311–320	230–237	-6.08	-9.21	-10.48
Over 320	Over 237	-8.78	-13.30	-15.14

Source: From "Farmland America's Best Pork Carcass Merit Program," effective 9/20/99 (Farmland Industries, Inc.).
[a] The discount applies to both lean and fat prices, with the fat price being reduced by half of the discount for lean. This discount is equivalent to the discount grid for payment scheme 1, assuming a 50% lean hog.
[b] The discount again applies to both lean and fat prices, with the fat price being reduced by one-quarter of the discount for lean. This discount is equivalent to the discount grid for payment scheme 1, assuming a 50% lean hog.

In payment schemes 2, 3, and 4, there are discounts for under- and over-weight carcasses as well, and the grid is the same as under payment scheme 1 (see table 2). Thus, when the live hog price is $43/cwt, the value of carcass lean is approximately $0.95/pound and $1.09/pound for payment schemes 3 and 4, respectively.[5] The carcass-

[5] Lean prices for payment schemes 3 and 4 are computed by setting the revenue of 250-pound controls (hogs not fed with Paylean) under payment schemes 3 and 4 to be the same as the revenue received from payment scheme 1. The premium and discount grids are also equivalent for payment schemes 1, 3, and 4 for hogs that are 50% lean.

Table 3. Discount/Premium Grid Used in Payment Scheme 2

Lean Percentage[a]	Lean Premium (Discount) ($/cwt of scalded carcass)
59% and Higher	+2.00
57 to 58.9%	+2.90
55 to 56.9%	+2.50
53 to 54.9%	+1.25
51 to 52.9%	0.00
49 to 50.9%	-1.25
47 to 48.9%	-2.50
45 to 46.9%	-5.00
43 to 44.9%	-7.50
Less than 43%	-10.00

Source: From "Farmland America's Best Pork Carcass Merit Program," effective 9/20/99 (Farmland Industries, Inc.).
[a] Lean percentage is calculated as: 58.86 – 0.61 × fat depth (mm) + 0.12 × muscle depth (mm). Both fat and muscle depths are the measurement between the 3rd and 4th ribs.

weight discounts for payment schemes 3 and 4 are expressed as a discount on lean and fat prices.

Payment schemes 1 and 2 are payment schedules used at a typical pork processor (based on the September 1999 data from Farmland Industries, Inc.). Payment schemes 3 and 4 are designed to reflect situations where a large share of the benefit from Paylean is captured by producers. With payment scheme 3, packers and retailers share with pork producers the downstream benefits associated with Paylean. In payment scheme 4, producers are assumed to capture the full benefit from Paylean because the ratio of lean to fat prices allows producers to receive all of the additional carcass cut-out value (Akridge, Forrest, and Judge; Brorsen et al.). Therefore, payment schemes 3 and 4 are hypothetical payment systems designed to reflect a high degree of vertical coordination or vertical integration.

Production costs include the cost of the feeder pig, feed expenditures, transportation cost, and a variable cost covering daily expenditures of the operation. Fixed costs such as facilities are not included. Feed is based on a standard corn-soybean meal diet, which includes synthetic lysine, a vitamin-mineral premix, and a processing cost. The calculation of feed composition and feed cost follows the work of Hill et al., where synthetic lysine is added at 0.117% of the digestible lysine level, and the proportion of corn and soybean meal is adjusted to achieve the desired dietary lysine percentage. The percentage of lysine in the feed is used as the indicator of the protein level, because it is typically the most limiting amino acid in swine feed formulations.

The model focuses on growth of hogs from the age of 104 days (around 143 pounds for gilts and 150 pounds for barrows) to the day they reach optimal market weight. The cost of the late-finishing pig is calculated by summing the feeder pig price, feed cost, and daily variable cost over the growing period from a 50-day-old feeder (50 pounds) to the age of 104 days. This value is estimated to be $58 and $59 for gilts and barrows, respectively.

Phase feeding is implemented in the model. Two alternative phase feeding scenarios are simulated: (*a*) a two-diet option, where the pig is fed different diets before and during Paylean supplementation, and (*b*) a three-diet option, where pigs are given one diet before Paylean and two diets during Paylean supplementation. In both cases, the second diet starting day is optimized, and Paylean feeding is initiated on the same day that the diet changes (except for control pigs which are not fed Paylean). Under the two-diet option, the second diet is fed up to the marketing date. Under the three-diet option, the switching day between the second and third diets is also optimized, and the third diet is fed until the marketing date. It is assumed that adding one diet will not incur any additional cost for grinding and mixing or management provided each diet is fed for a reasonably long period. Thus, a minimum of one week is imposed for the feeding periods for the second and third diets. The phase feeding program is designed to simulate the practices of small- to medium-sized hog production operations (two phases) and large operations (three phases).

Analysis Procedures

In every case, simulation of hog growth and the first phase of the feeding program starts when the hog is 104 days old. There are five (seven) management variables to be optimized in this modeling framework when a two- (three-) phase feeding program is used: the lysine level in the first diet, the day to initiate the second diet and Paylean supplementation, the Paylean concentration, the lysine concentration in the second diet, (the day to initiate the third diet and the lysine concentration in the third diet), and the day to market the hog. Given levels for each of these variables, the biological growth of the animal is simulated over time. A schematic representation of the biological growth model is displayed in figure 1. Production costs are also accumulated day-by-day, and potential revenues are calculated for each potential marketing day. A simultaneous grid search over all of the management variables is used to determine the optimal management strategy.[6]

Profitability Analysis

Simulation results show, for both production environments and all four payment schemes, Paylean-fed hogs yield higher returns than hogs not supplemented with Paylean. Table 4 reports the net economic gain from Paylean supplementation. The net economic gain is the difference between optimal return for hogs supplemented with Paylean and the optimal return for control hogs. The increases in annual net return per pig space range from $4.65 to $22.01 depending on the payment scheme and the number of diets fed. The net economic gain from Paylean use, detailed in table 4, can serve as a guide for producers in making decisions on Paylean adoption.

As observed from table 4, CF hogs have slightly higher net economic gain from Paylean adoption than SEW hogs. However, it is important to keep in mind that the base returns to control hogs are higher for SEW hogs than for CF hogs. Even with the slightly higher payoff from using Paylean for the CF hogs, the net returns for SEW hogs fed Paylean remain higher than those for CF hogs. Hence, farms with better growth environments still reap higher earnings with the adoption of Paylean.

[6] The computer program, written in GAMS (Brooke, Kendrick, and Meeraus), is available from the authors upon request.

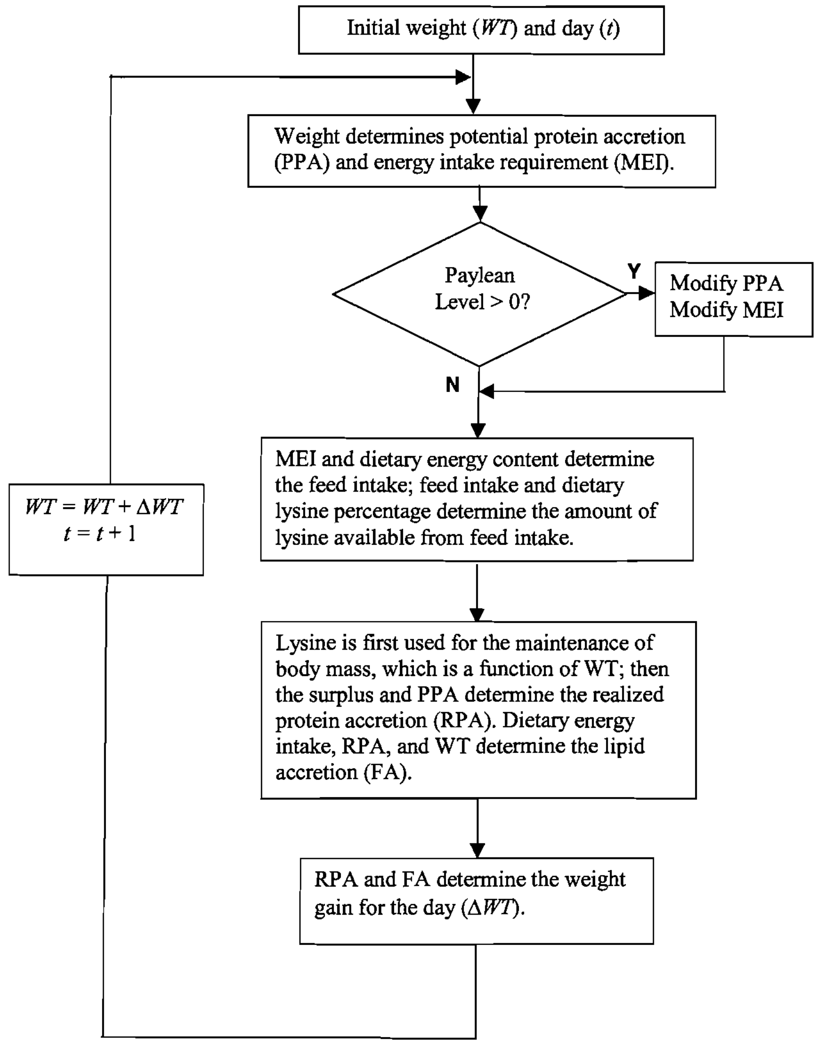

Figure 1. Schematic representation of the biological growth model

The optimal Paylean concentrations range from 5 ppm to 12 ppm and are within the legal ranges stipulated by the FDA. The lowest optimal level of 5 ppm occurs for hogs grown in both environments under payment schemes 1 and 2. Under payment scheme 3, the optimal concentrations range from 6 to 6.5 ppm, and for payment scheme 4, the concentrations increase to a range of 8 to 12 ppm. These results indicate optimal Paylean concentrations increase with the lean-to-fat price ratio paid to hog producers.

Gilts have the same or higher Paylean concentrations as barrows under payment scheme 3, and uniformly higher concentrations than barrows under payment scheme 4. Although gilts and barrows have the same optimal Paylean concentrations under some payment schemes, barrows have an earlier supplementation age than gilts and require a lower dietary protein level. Therefore, split-sex feeding is needed to achieve the full potential return. (When the management variables are optimized, including Paylean

Table 4. Increase in Net Returns Due to Paylean Adoption

Payment Scheme	Gilt (¢/pig space/day)	Barrow (¢/pig space/day)	Average of Gilt and Barrow ($/pig space/year)[a]
SEW Hogs with 2 Diets:			
1	1.47	1.12	4.65
2	3.95	3.54	13.44
3	3.07	2.82	10.57
4	5.03	4.59	17.27
SEW Hogs with 3 Diets:			
1	1.83	1.43	5.85
2	4.15	4.01	14.65
3	3.47	3.32	12.19
4	5.50	5.09	19.01
CF Hogs with 2 Diets:			
1	1.66	1.36	5.42
2	3.87	1.90	10.36
3	3.86	3.64	13.46
4	5.90	5.51	20.48
CF Hogs with 3 Diets:			
1	2.03	1.64	6.59
2	4.28	2.23	11.69
3	4.29	4.13	15.11
4	6.31	5.95	22.01

[a] The increased net return per pig space per day is computed as the average daily returns for Paylean-fed pigs less average daily return for control pigs. The net return per pig space per year is calculated as the daily difference times 359 days, which is the number of days the barn is assumed to be available for rearing pigs, leaving six days for cleaning and drying of pens.

management, but restricted to be the same across gilts and barrows, the average net returns per pig space per day are 0.81% lower than under split-sex feeding.) Under payment schemes 3 and 4, the optimal Paylean concentrations for CF hogs are slightly higher than those for SEW hogs in most cases. For most hogs under payment schemes 3 and 4, the Paylean concentrations for hogs fed three diets are higher than for hogs receiving two diets.

Paylean Feeding Duration and Nutrition Management

The length of the time interval over which Paylean is fed and the level of protein in the diet are the two most important factors in swine production management with Paylean technology. In this section, we consider the effects of fixed Paylean concentrations (5, 10, and 20 ppm) on the optimal duration of Paylean supplementation and dietary lysine management. The analysis employs simulation data from hogs fed with two diets; hence, the second diet is the only diet supplemented with Paylean and its feeding duration is the same as that for Paylean. The nutrition level in the second diet indicates the optimal feed management with Paylean adoption.

Table 5. Optimal Dietary Lysine Percentage in the Second Diet for Control and Paylean-Fed Hogs When Two Diets Are Fed (%)

Payment Scheme	Paylean Levels							
	0 ppm		5 ppm		10 ppm		20 ppm	
	Gilt	Barrow	Gilt	Barrow	Gilt	Barrow	Gilt	Barrow
SEW Hogs:								
1	0.56	0.54	0.78	0.73	0.81	0.76	0.81	0.74
2	0.59	0.54	0.82	0.73	0.82	0.76	0.84	0.78
3	0.59	0.54	0.83	0.78	0.82	0.78	0.90	0.85
4	0.60	0.56	0.89	0.82	0.99	0.89	1.05	0.96
CF Hogs:								
1	0.61	0.56	0.85	0.77	0.89	0.79	0.91	0.81
2	0.62	0.63	0.88	0.79	0.91	0.80	0.94	0.83
3	0.67	0.63	1.01	0.96	1.06	1.00	1.10	1.02
4	0.68	0.68	1.05	0.99	1.10	1.05	1.18	1.12

Dietary Protein Management

As stated in Elanco's "Paylean Nutrition Guide for Industry Professionals" (p. 15), "Pigs fed Paylean have nutrient requirements that are greater than their non-treated counterparts, because Paylean increases the rate of lean growth." The management of dietary protein is imperative in order to realize the full benefit from Paylean adoption.

Table 5 displays the optimal lysine concentrations in the second diet for 0, 5, 10, and 20 ppm Paylean concentrations. For SEW hogs given 5 ppm of Paylean, the optimal dietary lysine percentage is 0.19 to 0.29 higher than for control hogs. The increase in the dietary lysine percentage for SEW hogs supplemented with 10 ppm of Paylean, relative to control hogs, is in the range of 0.22 to 0.39, and between 0.20 and 0.45 for hogs fed 20 ppm. The optimal lysine percentages for CF hogs, both control and Paylean-treated, are higher than those for SEW hogs when other conditions are equal. The increases in dietary lysine percentage due to Paylean supplementation for CF hogs are similar to those for SEW hogs for each of the payment schemes. Adjusting the lysine level is important for obtaining the full benefit of Paylean supplementation. If hogs are fed Paylean in the range of 5–10 ppm, but the dietary lysine level for control hogs is used for the diets, then optimal returns are between 2.5% and 22.4% lower than with optimal adjustment of the lysine level.

For a given payment scheme, the optimal lysine level is jointly determined by the weight interval during which the diet is fed and the Paylean concentration. Because the starting weights of Paylean for each pig are in a close range (see table 6), the impact of weight on the dietary lysine percentage is negligible, and the increased dietary lysine levels for Paylean-fed hogs are primarily caused by the supplementation of Paylean.

In most economically optimal diets, lysine is a limiting nutrient. In this situation, increasing the lysine concentration in the diet promotes lean growth. Hence, as the value of lean relative to fat increases, the optimal lysine level will also increase. This effect is evident in table 5, where the optimal lysine level increases from payment scheme 1 to scheme 4. Moreover, the optimal lysine level increases with the concentration of Paylean in the diet.

Table 6. Optimal Market Weight and Weight to Initiate Paylean Supplementation for SEW and CF Hogs with Two Diets (pounds)

Payment Scheme	Paylean Levels							
	0 ppm [a]		5 ppm		10 ppm		20 ppm	
	Gilt	Barrow	Gilt	Barrow	Gilt	Barrow	Gilt	Barrow
Paylean Onset Live Weight for SEW Hogs: [b]								
1	198.1	202.3	198.8	202.8	205.7	212.3	230.4	247.0
2	201.0	202.3	194.3	202.8	205.7	212.3	219.3	226.5
3	198.6	202.3	182.9	183.8	201.0	202.6	201.2	205.2
4	200.9	205.0	169.3	181.4	160.2	174.4	164.8	176.8
Optimal Hot Carcass Slaughter Weight at Marketing Day for SEW Hogs [b]								
1	207.0	207.0	207.0	206.4	206.9	206.7	207.0	207.0
2	206.1	207.0	206.7	206.4	206.9	206.7	206.6	206.0
3	206.0	207.0	207.0	207.0	207.0	207.0	206.4	206.0
4	206.1	205.6	196.9	205.2	189.0	198.6	186.1	193.5
Paylean Onset Live Weight for CF Hogs: [b]								
1	193.1	199.9	184.7	193.2	189.7	199.9	199.5	212.6
2	191.4	193.4	179.5	189.7	184.7	196.6	193.1	208.0
3	183.0	186.3	151.7	152.3	153.7	156.3	165.1	171.7
4	184.8	188.1	151.7	152.3	151.7	152.3	151.7	152.3
Optimal Hot Carcass Slaughter Weight at Marketing Day for CF Hogs: [b]								
1	183.1	186.4	181.0	184.4	180.4	184.6	181.2	185.0
2	182.1	174.1	178.0	182.5	177.4	182.6	178.5	183.3
3	169.9	169.4	169.0	170.0	169.8	169.3	169.0	169.6
4	170.0	169.5	169.2	170.1	169.9	169.6	169.5	170.1

[a] For pigs without Paylean, the entries are starting weights for the second diet, with optimal lysine levels given in table 5.
[b] The Paylean onset weight is based on live weight of the animal. However, the optimal carcass weight is based on the hot carcass weight, or the weight of the animal with head and all visceral organs removed, and feet trimmed prior to chilling.

Based on the responses reported in field trials, the dietary protein requirement is modeled as an abrupt increase when Paylean starts, and then a gradual decrease as the pig grows heavier. Therefore, with three diets, the optimal lysine concentration in the third diet is always less than in the second diet. Assuming no cost in switching diets, the highest return can be obtained when diets are switched daily, with each diet economically targeted to the animal's growth needs for that day. From a practical perspective, however, feeding only two or three phases during finishing is typical.

In addition to the above factors, the optimal dietary protein levels in hog production also depend on the feeder pig cost, feed price, and price for finished hogs. Ideally, each producer should determine his or her own nutrition management plan in accordance with economic and environmental conditions when considering adoption of Paylean.

Duration of Paylean Feeding and Optimal Market Weight

The optimal live weights to start Paylean feeding for each farm and payment system are given in table 6. These results indicate that with a higher lean-to-fat price ratio and a lower concentration of Paylean, initiation of Paylean occurs at a lower weight. Initiation of Paylean supplementation for SEW hogs is always at a heavier weight than for CF hogs under the same payment scheme. The difference in the optimal weight to initiate Paylean between SEW and CF hogs ranges from 2.4 to 47.3 pounds, with the largest differences occurring under payment scheme 3 and the smallest under payment scheme 1. The average difference is 20 pounds.

The optimal hot carcass weight at slaughter is also presented in table 6. SEW hogs are marketed heavier than CF hogs, with average slaughter weights of 204.4 pounds and 175.6 pounds, respectively. The optimal hot carcass weights for CF hogs under payment schemes 3 and 4 are all at the lower end of the no-discount range (see table 2). The optimal hot carcass weights for SEW hogs under payment schemes 1, 2, and 3 are all at the upper end of the no-discount range. Hot carcass weights for CF hogs under payment schemes 1 and 2 and for SEW hogs fed Paylean under payment scheme 4 are well inside the no-discount weight range—i.e., several pounds above the lower end and several pounds below the upper end of the range. Thus, in the majority of cases, the discontinuous nature of the discount schedule has a large impact on determining the optimal slaughter weight, with most animals slaughtered either when they reach the bottom or the top of the no-discount weight range.

Sensitivity Analysis

The results presented in this analysis are for price averages over time. With widespread adoption of Paylean and other changes in the market, relative prices are likely to shift in the future. To assess the robustness of Paylean management choices and returns with Paylean adoption as prices change, sensitivity analyses are conducted with respect to five prices: corn price, soybean meal price, live hog price, feeder pig price, and Paylean price. For prices derived from historical averages, simulations are performed using prices one standard deviation higher and lower than the base case while holding the other prices constant (values of the standard deviations are given in table 1). The Paylean price is allowed to increase and decrease by 50% of its base level. Elasticities are calculated as the percentage changes in returns and management choices for Paylean concentration and duration with respect to 1% changes in prices.[7] The model with two-diet management is used for the sensitivity analyses.

Paylean Concentration and Duration of Feeding

The sensitivity analyses show that among all the prices considered, Paylean concentration is most sensitive to its own price. Paylean concentrations are more sensitive under payment schemes 3 and 4 than under payment schemes 1 and 2 (see table 7). The zero elasticities under payment schemes 1 and 2 reflect an anomaly of the model occurring at the 5 ppm level for Paylean. Specifically, the Paylean response is nondifferentiable at 5 ppm because the Paylean response in the biological growth model was estimated separately below and above 5 ppm with the requirement that the response should be

[7] The elasticities are arc elasticities which are calculated as the percentage change in the response variable divided by the percentage change in the price of interest, where the low price is one standard deviation below the base price and the high price is one standard deviation above the base.

Table 7. Elasticities of Optimal Dietary Paylean Concentration with Respect to Input and Output Prices for SEW and CF Hogs Fed Two Diets

	Payment Scheme							
	Scheme 1		Scheme 2		Scheme 3		Scheme 4	
Price Description	Gilt	Barrow	Gilt	Barrow	Gilt	Barrow	Gilt	Barrow
SEW Hogs:								
Soybean Meal Price	0.00	-0.25	0.25	0.00	0.21	0.21	-0.53	-0.47
Corn Price	0.00	0.00	-0.26	0.00	-0.22	-0.22	1.39	0.66
Paylean Price	-0.30	-0.40	-0.20	-3.00	-2.50	-2.50	-1.53	-1.81
Live Hog Price	0.00	0.00	0.00	0.00	0.25	0.98	4.02	4.04
Feeder Pig Price	0.00	0.00	0.00	0.00	0.00	0.19	-1.60	-1.31
CF Hogs:								
Soybean Meal Price	0.00	0.00	0.00	0.00	-0.39	0.00	-0.63	-0.56
Corn Price	0.00	0.00	0.00	0.00	0.20	0.00	-0.11	0.29
Paylean Price	-0.20	-0.40	-0.20	-0.40	-2.08	-2.42	-1.17	-1.61
Live Hog Price	0.00	0.00	0.29	0.00	0.90	0.74	1.47	1.80
Feeder Pig Price	0.00	0.00	0.00	0.00	-0.18	-0.19	0.49	0.00

continuous. (This estimation strategy was necessary due to the paucity of data sets that include Paylean concentrations strictly between 0 and 5 ppm.) Thus, there is a kink in the Paylean response function at 5 ppm. As a result, the Paylean concentration, while sensitive to its own price, is insensitive to changes in prices of other inputs when the base concentration level is 5 ppm.

For SEW hogs under payment scheme 4, the Paylean concentration is sensitive to changes in every price, with the highest elasticity associated with the live hog price and the lowest elasticity associated with the soybean meal price. When SEW hogs are sold under payment scheme 3, Paylean concentration is most sensitive to its own price and to live hog prices, and only moderately sensitive to the changes in feeder pig and feed ingredient prices. For CF hogs under payment schemes 3 and 4, the Paylean concentration is highly sensitive to the live hog price and its own price, and relatively insensitive to other prices. The optimal Paylean concentrations are less sensitive to price changes for CF hogs in general than for SEW hogs.

The signs of the elasticities of Paylean concentration with respect to soybean meal price changes are interesting to observe because soybean meal has relatively high lysine content, and a high protein diet is required to obtain the full benefit of Paylean. For SEW hogs, Paylean and soybean meal appear to be substitutes under payment schemes 2 and 3, and complements under payment schemes 1 and 4. However, the elasticities reported in table 7 are for the optimal dietary concentration of Paylean, not for total consumption of Paylean. Due to interactions among the Paylean concentration, supplementation period, and feed intake, the total amount of Paylean consumed falls in every case when the soybean meal price increases. Thus, Paylean and soybean meal are complements despite the observed relationship between soybean meal price and Paylean concentration.[8]

[8] The sensitivity of the number of days on Paylean supplementation to changes in the key input and output prices was also examined. None of the elasticities are greater than 1, and therefore Paylean duration is relatively stable in the face of changing prices. Elasticities of Paylean duration and return with respect to price changes are available from the authors upon request.

Returns per Pig Space per Day

Returns per pig space per day are analyzed with respect to changes in key prices. Returns from hog production are most sensitive to the live hog price, with elasticities ranging from 3.38 to 4.73. Returns are also sensitive to feeder pig prices, but to a lesser extent, with elasticities ranging from -1.91 to -1.19. Responses of returns to changes in feed ingredient prices are moderately sensitive and have values between -0.62 and -0.12. Within the 50% range of price change for Paylean, the elasticities are close to zero, indicating returns are insensitive to changes in the Paylean price. Returns from CF hogs are, in general, more sensitive to price changes than those of SEW hogs. The elasticities of returns with respect to corn price are greater than the corresponding elasticities with respect to soybean meal price.

Summary and Future Research

Under historical average prices, feeding Paylean appears to be a profitable innovation for many producers. Regardless of whether Paylean is adopted or not, the highest returns accrue to production systems with superior management and growing environments. In addition, a phase-feeding program makes a substantial contribution to increasing returns.

Paylean requires increasing the dietary lysine percentage to obtain the full potential benefit. The optimal Paylean concentration and net return from Paylean adoption increase with the ratio of lean value to fat value. It is optimal to initiate Paylean supplementation for CF hogs at a lighter weight and feed Paylean for a longer period compared with SEW hogs.

Based on results of the sensitivity analysis, the optimal Paylean concentration is sensitive under payment schemes 3 and 4 only, and the length of the optimal Paylean supplementation period is relatively stable. In addition, the returns from hog production are not sensitive to the price of Paylean, but are highly sensitive to finishing hog and feeder pig prices.

Future work should examine additional strategies for managing Paylean. Ideally, these approaches will be coupled with live animal studies that evaluate the biological responses to a broader range of Paylean supplementation strategies—including step-up programs where the Paylean concentrations are increased over time. Additional research is also needed to assess the effect of Paylean on the within-barn variability in hog growth. Ultimately, a stochastic model of hog growth should be developed that permits fine-tuning of herd-level marketing strategies and allows evaluation of Paylean's effect on herd variability and its impact on producers' net returns.

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