The Value of Protein in Feed Barley for Beef, Dairy, and Swine Feeding

Jeffrey T. LaFrance and Myles J. Watts

The impact of the protein content of feed barley on the costs of feeding beef, dairy cattle, and swine in Montana is evaluated. A model of least-cost feed rations is constructed to analyze the marginal value of additional protein content in feed barley. The results indicate that increasing the protein content of feed barley above 12% will not substantially increase the value of barley to feeders. This implies that the establishment and maintenance of a protein premium in the feed barley market would tend to result in lower average prices for feed barley because the feed value/protein relationship is concave and the market would be sustaining costs that the inherent value of the commodity could not support.

Key words: feed barley, least-cost rations, protein.

Farmers receive significant premiums for the protein content in wheat. Higher protein wheats generally bring a higher price than lower protein wheats; this difference is commonly referred to as a "protein premium." On the other hand, in the malting barley market, a negative premium is paid for higher protein malting barleys, lower protein varieties being preferred. In the market for feed barley, no premium is received for additional protein. An important question for barley growers and livestock feeders is whether or not differences in the protein and amino acid content of barley produce a sufficient difference in feed value to support a premium for protein in feed barley. This question has been considered recently in Canada with regard to federal grain grading and standards, in Sweden, where a recent law mandates protein premiums for barley, and in the state of Montana.

The demand for low protein wheat is largely derived from the market demand for biscuits, cakes, pastries, and other baked goods which do not require a great deal of leavening (Bale and Ryan). The demand for high protein wheats is derived from the demand for bread and other baked goods which require more rising. The protein in wheat is the source of nitrogen and enzymes for yeast metabolization which results in the even rising of dough.

The demand for low protein malting barley is derived from the demand for beer. Price differentials reflect the ability of a shipment of malting barley to germinate in the malt house, and vary with respect to grades, varieties, protein level, and kernel plumpness (Wilson and Crabtree). A minimum level of protein, about 9%, is essential as a source of nitrogen for yeast metabolism and growth during fermentation and of the enzymes necessary to convert starch into fermentable sugars. Barley with a high protein level is undesirable because it can lead to cloudy beer. Maltsters generally attempt to avoid barleys with protein content exceeding 14% (Heid and Leath) and pay premiums for lower levels.

The demand for feed barley is derived from the demand for feed grains for beef, dairy cattle, and swine. When feeding livestock, greater rates of gain and levels of milk production imply greater protein requirements, which suggests that feed barley with a higher protein level would be more valuable to feeders. This study examines the demand for feed barley in

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order to identify the reasons for the current absence of a protein premium and to evaluate the desirability of establishing and operating a protein premium for feed barley. Because there is now no protein premium in the feed barley market, the approach that we take is to construct a model of least-cost feed rations and use it to analyze the marginal value of additional protein in feed barley to livestock feeders. The paper is organized as follows. Section two presents the model and methodology used to estimate the value to feeders of protein content in feed barley. The third section discusses the data and presents the results of the analysis, and the fourth section contains a summary and concluding remarks.

The Model

Formulations of animal diets are generally based upon von Leibig's "Law of the Minimum," which roughly states that the nutrient in the shortest supply constrains the rate of growth (or other production) of a plant or animal. If we let y denote the performance goal (weight gain in beef and swine and milk production in dairy), w the liveweight of the animal, and b_i the quantity of the ith nutrient consumed per day, $i = 1, \ldots, m$, then the law of the minimum states that

$$(1) \quad y = \text{minimum } [\psi_1(w, b_1), \psi_2(w, b_2), \ldots, \psi_m(w, b_m)]$$

where $\psi_i(w, b_i)$ is a function that expresses the relationship between the performance of the animal, the animal's weight, and the amount of the ith nutrient consumed. With this model, we can translate information on the animal's weight and desired performance into specific requirements for each of the nutrients necessary to obtain that performance.[1]

Let x_j denote the quantity of the jth foodstuff, a_{ij} the quantity of the ith nutrient contained in one unit of the jth food, and p_j the price of the jth foodstuff, for $i = 1, \ldots, m$ and $j = 1, \ldots, n$. The objective of finding the least-cost feed ration that contains the nutrients b_i, $i = 1, \ldots, m$, necessary to obtain the performance level y at current liveweight w can be stated as the linear programming problem,

$$(2) \quad \text{minimize } p'x \text{ subject to } Ax \geq b,\ x \geq 0.$$

The vector of cost-minimizing feeds is a function of prices, nutrient requirements, and the nutrient content of the feeds, $x^* = f(p, b, a)$, where

$$a \equiv \text{vec}(A) \equiv (a_{11}, a_{21}, \ldots, a_{m1}, a_{12}, \ldots, a_{m2}, a_{1n}, \ldots, a_{mn})',$$

and $'$ denotes matrix transposition. Substituting the choice functions for x into the objective function, we obtain the cost function $c(p, b, a) \equiv p'f(p, b, a)$.

Without loss in generality, let x_1 be the quantity of feed barley in the diet, and let a_{11} be the amount of protein contained in one unit of feed barley. Suppose that the protein content of barley changes from a_{11}^0 to a_{11}^1 with everything else held constant. A natural question that arises is how much effect does this change have on the cost of obtaining the nutrient requirement vector, b? In particular, we are interested in the price of barley that would make the feeder indifferent between a_{11}^0 and a_{11}^1. We define this price p_1^1, by the identity

$$(3) \quad c(p, b, a_{11}^0, a_{21}, \ldots, a_{mn}) \equiv c(p_1^1, p_2, \ldots, p_n, b, a_{11}^1, a_{21}, \ldots, a_{mn}).$$

If the change in the quantity of protein contained in one unit of feed barley does not affect the cost of obtaining the nutrient requirements vector, then there will be no change in the value of the feed barley. This will occur if barley is not fed in the least-cost ration both before and after the change in its protein content or the protein requirement constraint is slack in both least-cost solutions. If the protein requirement is binding and feed barley is used in positive quantity either before or after the change in protein content, then the change in a_{11} will influence $c(p, b, a)$.

This definition of the value of protein in feed barley is appropriate when a change in protein content does not result in a change in the content of other important nutrients. However, unlike beef and dairy cattle, swine cannot synthesize essential amino acids. The amount of these amino acids contained in feed barley varies with the protein content. Hence, it is desirable to have a theory for the value of a foodstuff in relation to its general nutrient content. The extension of the above concepts to this situation is straightforward. In particular, sup-

[1] This model uses the typical approach to ration formulation, which transfers desired levels of livestock performance into nutrient requirements based upon von Leibig's law. Von Leibig's law does not allow for substitutability between nutrients. The accuracy of the conclusions is limited by the realism of applying von Leibig's law to livestock performance.

pose that the nutrient content of barley changes from $a^0_{\cdot 1} = (a^0_{11}, \ldots, a^0_{m1})'$ to $a^1_{\cdot 1} = (a^1_{11}, \ldots, a^1_{m1})'$. Then we define the constant feed cost price of barley, p^1_1, by the identity

$$(4) \qquad c(p, b, a^0) \equiv c(p^1_1, p_2, \ldots, p_n, b, a^1)$$

where $a^j = (a^j_{11}, \ldots, a^j_{m1}, a_{12}, \ldots, a_{mn})', j = 0, 1$.

This procedure provides an estimate of the marginal value per unit of barley fed for additional protein and the associated amino acids contained in each unit of barley. By calculating the constant feed cost for feed barley at different levels of protein content, and different weights and performance rates for the animal, a good deal of information is obtained about the value of higher protein content in feed barley.

There are two questions of interest that can be studied with this procedure. First, what is the relationship between the optimal feed cost for beef, dairy, and swine and the protein content of barley at different liveweights, rates of gain, or performance rates? Second, does this relationship vary significantly with the animal's liveweight and/or performance rate? The answer to the first question indicates whether or not there is any demand-related basis for considering protein premiums for feed barley. The answer to the second question indicates what sort of structure such a price function would naturally have. Also, if it is found that the constant feed-cost price function for barley protein is independent of the animal's liveweight and performance, then the constructed price relationship identifies the marginal value of protein in feed barley to livestock feeders without the need to develop a more complex profit-maximization model.

The definition of p^1_1 is constructed from the linear programming model as follows: let $c^0 = \Sigma^n_1 p^0_j x^0_j$ and $c^1 = \Sigma^n_1 p^0_j x^1_j$. Then define p^1_1 such that $c^0 = p^1_1 x^1_1 + \Sigma^n_2 p^0_j x^1_j$. So long as changing p_1 from p^0_1 to p^1_1 does not change the basis solution under the new nutrient content vector for feed barley, it follows that

$$(5) \qquad p^1_1 = p^0_1 + (c^0 - c^1)/x^1_1.$$

If the basis solution changes with the move from p^0_1 to p^1_1, then a single evaluation of (5) overestimates the required change in p_1 to attain a constant level of feed costs, and a second iteration is required to obtain p^1_1.

This generalizes in the obvious way to the cases where the affected nutrient constraints are not binding before or after the change, or both, and where the jth foodstuff is not utilized in the least-cost ration before or after the change, or both. The critical bit of additional information necessary to deal with these cases is the precise level of nutrient content and price for feed barley that leads to a just binding (equivalently, just slack) constraint, or the quantity of the jth foodstuff just zero (equivalently, just positive). Since the current problem is one dimensional, these points are easily found through a simple search procedure.

The next section reports the results of applying this procedure to representative liveweights and performance rates for beef, dairy, and swine. The methodology is used to calculate prices $p^j_1, j = 1, \ldots, J,$ for protein levels in feed barley, $a^1_{11} < a^2_{11} < \ldots < a^J_{11}$, such that the cost of attaining the optimal (least-cost) feed ration is equal for all protein levels, given the animal's liveweight and performance rate.

Data and Results

The feeds and prices included in this study are: midbloom alfalfa hay, \$70.00 per ton; dehydrated alfalfa meal, \$5.85 per hundred weight (cwt); barley, \$5.05 per cwt; corn, \$5.80 per cwt; dicalcium phosphate, \$18.20 per cwt; l-lysine supplement for swine, \$1.75 per pound; native intermountain hay, \$60.00 per ton; oats, \$5.85 per cwt; soybean meal, \$13.90 per cwt; wheat, \$6.95 per cwt; and a vitamin and mineral premix supplement for swine, \$62.50 per cwt.[2] The prices are calculated as a simple average of the respective prices in Montana for the years 1977 to 1983 (Montana Department of Agriculture), adjusted to 1983 dollars by the index of prices received for feed grains and hay (U.S. Department of Agriculture).

The nutrient requirements included in this study are metabolizable energy, total digestible nutrients, protein, calcium, phosphorus, dry matter, and vitamin A for beef and dairy cattle. For swine, the vitamin and mineral premix supplement is fed at one percent of the total weight of the feed ration and provides adequate levels of the vitamins A, D, E, K, B_6, B_{12}, riboflavin, niacin, pantothenic acid, cho-

[2] Corn silage at \$20.00 per ton was also included as a feed source for beef and dairy, but the only major effect on the results was to reduce the use of barley in feeding.

Table 1. Constant Feed-Cost Barley Prices for Milk Cow Diets

Weight (lbs.)	1,250			1,500			1,750		
Milk/day (lbs.)	40	50	60	40	50	60	40	50	60
Barley Protein (%)	($/cwt)								
8	4.845	4.469	3.984	5.009	4.845	4.291	5.050	4.889	4.705
9	4.896	4.719	4.250	5.050	4.896	4.545	5.050	4.939	4.896
10	4.948	4.948	4.517	5.050	4.948	4.799	5.050	4.990	4.948
11	4.999	4.999	4.783	5.050	4.999	4.999	5.050	5.040	4.999
12	5.050	5.050	5.050	5.050	5.050	5.050	5.050	5.050	5.050
13	5.053	5.101	5.317	5.050	5.080	5.101	5.050	5.050	5.102
14	5.053	5.145	5.483	5.050	5.080	5.147	5.050	5.050	5.102
15	5.053	5.145	5.483	5.050	5.080	5.147	5.050	5.050	5.102
16	5.053	5.145	5.483	5.050	5.080	5.147	5.050	5.050	5.102

line, thiamin, biotin, and folacin, and adequate levels of the minerals sodium, chlorine, potassium, magnesium, iron, zinc, manganese, copper, iodine, and selenium. The premix provides these nutrients at a low cost, $0.03 to $0.04 per animal day, and allows a great deal of simplification in the analysis of swine feeding without loss of any essential detail. Thus, the nutrients explicitly included in the analysis of swine feeding are the same as for beef and dairy, excluding vitamin A and total digestible nutrients, plus the essential amino acids arginine, histidine, isoleucine, leucine, lysine, methionine + cystine, phenylalanine + tyrosine, threonine, tryptophan, and valine. In addition, 30% of the phosphorus in a swine diet must come from inorganic sources (National Research Council 1976, 1978, 1979).

For beef, the liveweights 700, 850, and 1,000 pounds and the growth rates 2.0, 2.5, and 3.0 pounds per day were included in the analysis. For dairy, the liveweights 1,250, 1,500, and 1,750 pounds and the milk production rates 40, 50, and 60 pounds per day at an assumed milkfat content of 3.5% were included. For swine, the liveweight ranges 75–130 pounds and 130–220 pounds were included with ad libitum feeding. For the beef and dairy analyses, when the NRC tables did not include the desired liveweight or growth/production rate, the nutrient requirements for that liveweight and growth/production rate were calculated by linear interpolation.

The level of barley protein was assumed to vary from 8% to 16% at one percent intervals, with 12% considered to be the standard level of protein content. The percentages lower or higher than 12% were included to bracket a reasonable range of values. It was assumed throughout the study that all other levels of nutrient content remain unchanged and that content of each amino acid as a proportion of total protein is constant.[3]

In the analysis of feed rations for beef cattle, it was found that the protein constraint was not binding for any level of protein content in feed barley from 8% to 16%, although barley was always used in the least-cost ration. Consequently, the feed value of barley for beef is invariant with respect to protein content, and the constant feed cost price of barley is $5.05 per cwt for all levels of protein. This finding supports the contention by animal nutritionists that the principal value of barley as feed for beef cattle is from its energy content rather than protein (Canada Grains Council, p. 182).

Table 1 presents the results obtained for the constant feed cost prices for barley from the analysis of dairy feeding. It is clear from table 1 that protein is more important to dairy farmers than beef producers, especially for the low ranges of protein content in feed barley and the higher levels of milk production. However, the value of barley peaks when the protein content is 13%, except at the milk production levels of 50 and 60 pounds per day

[3] The assumption that the availability of other nutrients is not affected by the level of protein content in barley is likely to be an oversimplification, particularly in swine diets. Lysine, for example, decreases as a percentage of protein with increasing total protein. As a result, the added value of feed barley due to greater protein content is overstated. This simplification overestimates the influence of changes in barley protein on the costs of feeding beef, dairy, and swine.

Table 2. Constant Feed-Cost Barley Prices for Swine Diets

Barley Protein	75–130 lb. Liveweight	130–220 lb. Liveweight
(%)	($/cwt)	
8	4.299	4.400
9	4.527	4.589
10	4.741	4.761
11	4.882	4.897
12	5.050	5.050
13	5.168	5.074
14	5.223	5.125
15	5.278	5.175
16	5.333	5.225

for 1,250-pound cows and 60 pounds per day for 1,500- pound cows, which peak when barley protein content is 14%. Therefore, barleys with protein levels less than 12% to 13% will have substantially less value to dairy farmers, while in most cases barleys with protein levels greater than 13% will have only slightly greater value.[4]

Table 2 presents the results of the analysis of feed costs for swine fed ad libitum. In this analysis, protein content in barley has considerable value in the range from 8% to 12%, and the equilibrium prices in this range are only slightly dependent on the size of the animal. At 12% protein content in barley, the protein requirement becomes nonbinding for 130–220-pound animals, although the lysine requirement remains binding throughout the 8% to 16% range of protein content in feed barley. For 75–130-pound animals, the protein requirement becomes nonbinding at 13% protein content in barley, with the lysine requirement binding throughout the range of 8% to 16% protein content in feed barley. As a result, the value of feed barley to swine feeders tends to increase significantly from 8% to 13% protein content, increasing at a considerably lower rate from 13% to 16%.[5]

Table 3 presents quantity weighted average prices for barley with respect to protein content for beef, dairy, and swine feeding for Montana. The quantity weights for each protein level were determined by the amount of barley fed in the least-cost diet for each animal, each liveweight, and each rate of growth or milk production. For the barley prices aggregated across all beef, dairy, and swine, the quantity weights were determined by the product of the amount of barley fed in each least-cost feed ration times the number of cattle on feed, producing milk cows, and hogs and pigs in Montana as of 1 January 1983 (Montana Department of Agriculture, p. 8), respectively. From these estimates we can conclude that barley with protein content below 12% has considerably lower feed value for swine and somewhat lower feed value for dairy, but barley with protein content above 12% does not have a much higher feed value for beef, dairy, or swine.

Table 3. Weighted Average Constant Feed-Cost Barley Prices for Beef, Dairy, and Swine Diets

Barley Protein	Quantity Weighted Average Barley Prices: Beef	Dairy	Swine	Aggregate
(%)	($/cwt)			
8	5.050	4.577	4.360	4.542
9	5.050	4.735	4.568	4.700
10	5.050	4.869	4.751	4.838
11	5.050	5.972	4.889	4.942
12	5.050	5.050	5.050	5.050
13	5.050	5.122	5.121	5.110
14	5.050	5.159	5.188	5.156
15	5.050	5.159	5.218	5.172
16	5.050	5.159	5.279	5.203

Increases in the value of feed barley due to increasing protein content

	8%–12% Protein		12%–13% Protein		12%–16% Protein	
	($/cwt)	(%)	($/cwt)	(%)	($/cwt)	(%)
Beef	.000	.0	.000	.0	.000	.0
Dairy	.473	9.8	.072	1.4	.109	2.1
Swine	.690	14.7	.071	1.4	.229	4.4
Aggregate	.508	10.6	.060	1.2	.153	3.0

Conclusions

For a protein premium to be desirable in an effectively operating market, the value of feeding higher protein barley must be greater than the transaction costs of establishing the premium. Measuring protein levels and separate-

[4] The nutrient requirements of dairy cows vary over the lactation period. Protein content is more important for a cow that has just freshened. The NRC tables contain averages over the lactation cycle which do not reflect the different requirements at different times in a cow's lactation.

[5] There is evidence that low protein barley has higher protein quality than high protein barley (Husby et al.). For example, 8% protein barley can have 4% lysine content in the protein, while 16% protein barley may have only 3% lysine content in the protein. In this study it is assumed that amino acids are a constant proportion of the protein content.

ly storing and handling barleys of different protein contents would be costly. Because there is little or no cost savings to feeders from using barleys with protein content higher than 12%, there would tend to be a lack of demand for higher protein levels in feed barley by feeders and, hence, by intermediaries such as the grain elevator operators. When this is compounded with the fact that the establishment and maintenance of a protein premium for feed barley cannot be accomplished at a zero cost, it is most likely that such a premium would actually decrease the average price for feed barley.

This conclusion follows from two aspects of the analysis presented above. First, feed barley with a protein level significantly lower than 12% also has significantly lower feed value for dairy and swine, and in the aggregate feed barley market, while feed barley with a protein level higher than 12% does not have significantly higher feed value. Thus, the protein content/feed value relationship for barley is concave and, by Jensen's inequality, the value of the average level of protein content is greater than the average value of all protein contents for feed barley. For example, the average protein content of barley is 12% with a price of $5.05 per cwt, but the simple average of the aggregate prices across protein levels in table 3 is $4.92 per cwt, which is considerably less.

Second, the establishment and maintenance of a protein premium for feed barley would be associated with the attendant costs of measurement, handling, and storage, but the added use value of higher protein feed barley does not appear to be large enough to support such costs. A protein premium in the feed barley market does not appear to be economically justified, and the results of this study suggest that efforts to develop a marketing arrangement which includes such a premium are neither warranted nor desirable.

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References

Bale, M. D., and M. E. Ryan. "Wheat Protein Premiums and Price Differentials." *Amer. J. Agr. Econ.* 59(1977): 530–32.

Canada Grains Council. *Grain Grading for Efficiency and Profit.* Winnipeg, Manitoba, Canada, (Sep. 1982).

Heid, W. G., and M. N. Leath. *U.S. Barley Industry.* Washington DC: U.S. Department of Agriculture, Agr. Econ. ESCS Rep. No. 395, 1978.

Husby, F. M., C. C. Calvert, C. W. Newman, W. F. Gipp, R. L. Harrold, and J. A. Froseth. *Utilization of Barley in Swine Diets.* SAES Western Reg. Res. Pub. No. 4, 1985.

Leibig, J. von. *Organic Chemistry in its Application to Agriculture and Physiology.* London: Playfair, 1840.

Montana Department of Agriculture, Crop and Livestock Reporting Service. *Montana Agricultural Statistics,* vol. 20. Helena MT, 1983.

National Research Council. *Nutrient Requirements of Beef Cattle,* 5th rev. ed. Washington DC: National Academy of Sciences, 1976.

———. *Nutrient Requirements of Dairy Cattle,* 5th rev. ed. Washington DC: National Academy of Sciences, 1978.

———. *Nutrient Requirements of Swine,* 8th rev. ed. Washington DC: National Academy of Sciences, 1979.

U.S. Department of Agriculture. *Agricultural Statistics.* Washington DC, 1983.

Wilson, W., and J. Crabtree. *Price-Quality Relationships in the U.S. Barley Market.* Dep. Agr. Econ. Rep. No. 168, North Dakota State University, 1983.