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Alfalfa Hay Quality and Alternative Pricing Systems

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Price-quality relationships for alfalfa hay were analyzed by hedonic pricing models using 1996–2001 Wisconsin auction data. Individual nutrients included in the analysis all affected alfalfa price, with acid detergent fiber accounting for the largest impact. Alternative pricing models, based on an aggregate quality index or detailed quality information, were similar in their ability to predict price. However, disaggregating price predictions to account for differences in relative feed value (*RFV*) and crude protein (*CP*) indicate that both *RFV* and *CP* are important determinants of price and that aggregating the two into a quality index is not warranted.

Key Words: aggregate index, alfalfa, auction data, hedonic pricing models, quality

JEL Classification: Q11

Alfalfa, sometimes referred to as "Queen of the Forage Crops," is the most widely produced forage crop in the United States (Lacefield). Alfalfa's adaptability to many weather conditions and soil types allows it to be grown in many regions of the country. In 2001, the National Agricultural Statistics Service reported that alfalfa was produced in 42 states and constituted 53% of all hay produced in the United States. Its high nutritional quality makes it a valuable livestock feed. The North American Alfalfa Improvement Conference reported an estimated value of alfalfa of $8.1 billion in 2000.

Over the last several years, the alfalfa industry has placed greater emphasis on producing higher quality alfalfa, rather than larger quantities (Lacefield). The American Forage and Grassland Council, along with other groups and organizations, developed alfalfa quality standards based on several years of quality analysis. Standards are established for percentages of three nutritional factors, crude protein (*CP*), acid detergent fiber (*ADF*), and neutral detergent fiber (*NDF*), and for an index called the relative feed value (*RFV*), which is calculated from *ADF* and *NDF* percentages. *CP* in alfalfa helps to meet animals' protein needs. *ADF* and *NDF* represent highly indigestible and partially digestible plant material in feed. *RFV* is a calculated value that measures forage quality in terms of potential dry-

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Table 1. Quality Standards Assigned by the American Forage and Grassland Council[a]

Standard	*RFV*	*CP* (%)	*ADF* (%)	*NDF* (%)
Prime	>151	>19	<31	<40
1	125–151	17–19	31–35	40–46
2	103–124	14–16	36–40	47–53
3	87–102	11–13	41–42	54–60
4	75–86	8–10	43–45	61–65
5	<75	<8	>45	>65

Source: Lacefield, G.D. "Alfalfa Hay Quality Makes the Difference." University of Kentucky Department of Agronomy AGR-137, Lexington, KY, July 1988.

[a] *RFV* is relative feed value; *CP* is crude protein; *ADF* is acid detergent fiber; and *NDF* is neutral detergent fiber.

matter intake (Lacefield).[1] Each factor is categorized into six levels of quality standards: Prime, 1, 2, 3, 4, and 5. Highest values of *CP* and *RFV* and lowest values of *ADF* and *NDF* correspond to the best quality standard, Prime (Table 1). The relationship between these quality standards and alfalfa price is the focus of this paper.

Alfalfa hay is used as feed for a variety of livestock. The primary consumers of alfalfa hay are dairy cattle, horses, and beef cattle. Each livestock requires feed of different nutritional value. Dairy farmers demand good-to-excellent quality alfalfa to mix in feed rations for milk production. Mixing high-quality alfalfa into a feed ration with corn silage and grain increases digestible energy, which results in greater milk production than using lower quality alfalfa (Cherney and Hall). Most horse owners also demand high-quality alfalfa hay. The beef cattle market generally does not demand quality as high as that demanded for other livestock and is a possible market for poorer quality hay. For example, a survey of animal scientists and extension livestock specialists regarding preferred nutritional contents of alfalfa for different species reported average preferred *CP* percentages of 19.8 for dairy cattle, 16.3 for beef cattle, 16.4 for feedlot cattle, 16.7 for horses, and 17.2 for sheep (Ward, Kariuki, and Huhnke). Buyers aim to purchase alfalfa with quality that suits their needs.

Most factors that influence the supply of quality characteristics of alfalfa hay depend on farmers' management. Management issues include variety selection, pest management, maturity, cutting schedule, harvesting techniques, and storage. Pests such as alfalfa weevil, potato leafhopper, aphids, and other insects can defoliate alfalfa and reduce nutritional characteristics. Thin alfalfa stands decrease yield and also allow for weed invasion. Weeds, or foreign material, decrease quality and make alfalfa more difficult to market. The timing of harvest is critical, because maturity of the plant at harvest determines the palatability, amount of nutrients, and yield. If alfalfa is not harvested at its peak quality, nutritional characteristics could decline significantly each day as alfalfa matures; an optimal cutting schedule involves a tradeoff between yield and quality (Blank, Orloff, and Putnam). Leaf loss that occurs with improper harvesting, such as raking and baling when plants are too dry, can seriously diminish hay quality. Storing at the proper moisture content helps retain alfalfa quality, whereas allowing water to come into contact with alfalfa after harvest can dramatically decrease quality.

With demand and supply for different quality attributes of alfalfa hay, the market should send appropriate price signals for various quality attributes. Indeed, previous studies have confirmed a relationship between alfalfa price and quality. In a study of a Pennsylvania hay auction during 1982 and 1983, alfalfa hay brought a higher price than legume grasses and straw (Grisley, Stefanou, and Dickerson). However, no measure of hay quality was included. Ward (1987) analyzed transactions that occurred through a computer-assisted alfalfa-marketing program, HAYMARKET, in Oklahoma from 1983 to 1986. His results indicated that Oklahoma buyers paid premiums for alfalfa with greater protein levels. Klemme, Chavas, and Moriarty analyzed 1983–1986 data from a Wisconsin hay auction in a hedonic pricing model and concluded that pos-

[1] Relative Feed Value (*RFV*) is computed as $RFV = (DDM \times DMI)/1.29$, where *DDM* and *DMI* are digestible dry matter and dry-matter intake, respectively, calculated from *NDF* and *ADF* percentages as $DDM = 88.9–0.779\ ADF$ and $DMI = 120/\text{NDF}$.

itive relationships existed between hay price and quality characteristics and various market variables. It was also established that the relationships were stronger with higher hay quality. Ward (1994) further examined quality variables individually by using 1992 and 1993 data. He found that alfalfa price was positively correlated with larger values of *RFV* and percentages of *CP* and was negatively correlated with greater values of *ADF* and *NDF*.

Recently the alfalfa industry has been increasing its reliance on *RFV* as a tool for evaluating and marketing hay (Gray and Hill; Moore, Burnes, and Fisher). Despite its wide acceptance, however, some question the underlying assumptions that invalidate comparisons between alfalfa and other forage. There are also large discrepancies across regions in how hay is sampled and what quality characteristics are preferred. For example, Hoffman et al. indicate that the National Research Council, in the 2001 Nutrient Requirements of Dairy Cattle, used a cumulative measure of forage digestibility based on energy contributed from protein, fat, nonfiber carbohydrates, and *NDF*. A survey of dairy producers ranked the quality objectives in alfalfa purchases as *CP* percentages, total digestible nutrients, and *RFV* (Ward, Huhnke, and Cuperus). Also, *RFV* is not used in the formulation of rations. A heavy reliance on *RFV* as a pricing tool may be placing some producers and consumers at a disadvantage, because some hay may be over- or underpriced for other nutritional factors not accounted for by *RFV*. For example, alfalfa with a high *RFV* (and hence expensive) may meet nutritional guidelines associated with dry-matter intake but may not have the amount of protein needed. Hay with a high amount of protein but with a low *RFV* may be a "bargain" for users, whereas producers may not be adequately compensated for a higher protein level.

The objectives of this paper were to determine how alfalfa quality characteristics affect alfalfa hay prices and to evaluate performance of alternative alfalfa pricing systems. Specifically, a pricing system based on an aggregate quality index was compared with pricing systems based on standards and values of individual quality attributes. Alfalfa prices at two auction locations in Wisconsin from 1996 through 2001 were analyzed in relation to measured nutritional content and industry standards. Given alfalfa's significant market value, it is critical to update previous studies to evaluate how the current alfalfa market relates price to quality attributes. Knowledge of which quality characteristics have the most impact on price would allow producers to make more efficient production and marketing decisions and would aid alfalfa users in resource allocation. This study differs from previous studies by measuring price and quality relationships using a recent sample and by applying the results to evaluate the current pricing system, which depends on the aggregate quality index, *RFV*. In addition, price and quality relationships in shorter and larger supply years were compared.

In the subsequent sections, data from Wisconsin hay auctions are discussed, methods using various regression models are explained, and results of the analysis are presented. The discussion of results includes further implications of the current pricing system with an emphasis on *RFV* standards and comparison of quality values in shorter and larger supply years.

Data

Data used in this study were obtained from two quality-tested alfalfa auctions in Sheboygan County and Lomira, WI. Sale data from Wisconsin were used because of the availability of quality-tested auction data.[2] Auctions were held biweekly in Lomira and monthly in Sheboygan County during December–April when demand for baled alfalfa is strongest.

[2] Quality-tested auctions are held in states such as Wisconsin, Iowa, and Minnesota, which have relatively small-scale producers and buyers, whereas states such as Kansas, with a greater proportion of larger scale producers and buyers, do not have quality-tested hay auctions. Other marketing tools that relay alfalfa quality information from producers to potential buyers include HAYMARKET (Ward 1987), which allows producers and consumers to exchange information on quality-tested alfalfa hay.

Both auctions were operated in the same manner. Lots arrived early in the day and were probed to obtain samples. The samples were run through a mobile near infrared reflectance spectroscopy machine to obtain measurements of nutritional contents.[3] Printouts of these quality measurements were placed on each respective lot and made available for all buyers prior to selling. Lots were then auctioned off in order of arrival.

Our sample consisted of auction results from December 1996 through April 2001 at both locations, which included information for each lot on price per ton; tons sold; bale type; nutritional characteristics (percentages of *CP*, *ADF*, *NDF*); and *RFV*. Only auction results containing all information for each lot were used. A total of 1,269 observations was obtained over the 5-year period.

[3] Several methods exist to quantify alfalfa characteristics. In years past, samples were sent to a laboratory to complete a quality analysis. However, near infrared reflectance spectroscopy (NIRS) is a faster and more mobile method to determine hay quality. NIRS laboratory evaluation measures the amounts of crude protein, acid detergent fiber, and neutral detergent fiber, among other components.

Summary statistics are presented in Table 2. More than 83% of observations are higher than, or equal to, Standard 2 by all measures, and the average values of all nutritional factors fall approximately between Standards 1 and 2. There is a slight discrepancy among the numbers of observations classified as Prime by *RFV* and its individual components, *ADF* and *NDF*. There are more than twice as many lots identified as Prime by *CP* percentages than by digestive intake measures in this sample. Two thirds of the observations are small square bales.

Model Specification

The conceptual framework for analyzing price-quality relationships is based on separate works by Lancaster, Griliches, and Rosen. Quality attributes may be considered as utility-providing elements in consumers' maximization problem (Ladd and Suvannunt), as inputs in production processes (Ladd and Martin), or as a market-equilibrium outcome between supply and demand for quality attributes (Rosen). In all approaches, the framework yields a he-

Table 2. Summary Statistics of Wisconsin Alfalfa Hay Auction Data, 1996/1997 to 2000/2001[a]

	Price ($/ton)	*RFV*	*CP* (%)	*ADF* (%)	*NDF* (%)	Lot Size (ton)
Average	84.85	124.59	17.48	35.71	46.62	5.27
SD	36.78	21.88	3.12	4.23	6.21	3.19
Number of observations by quality standards						
Prime		159	434	158	173	
1		455	324	528	548	
2		442	342	445	390	
3		173	121	78	130	
4		33	42	28	16	
5		7	6	32	12	
Number of observations by location						
Sheboygan County						416
Lomira						853
Number of observations by bale type						
Small square bales						843
Large square bales						326
Large round bales						100
Total number of observations						1,269

[a] *RFV* is relative feed value; *CP* is crude protein; *ADF* is acid detergent fiber; and *NDF* is neutral detergent fiber.

donic price function that relates price as a function of quality attributes.

Applying the hedonic framework, we specified nominal alfalfa price (P) as a function of nutritional-quality attributes and other physical characteristics, such as lot size and bale type, for which data were available. There are other criteria, such as color and presence of mold, that influence alfalfa price but were not recorded in the auction data set. To compare performance of various pricing systems, quality attributes were modeled in four ways: the current pricing system that relies on standards based on *RFV* (Model A), an alternative pricing system that incorporates standards of individual nutritional factors (Model B), a model that allows price to depend not on standards but on values of individual nutritional factors (Model C), and a model using Box-Cox transformation to explore flexible functional form (Model D).

In all models, lot size (*TON*) and binary variables for bale type were included. Expected effect of lot size on alfalfa price might be negative if there was a volume discount or positive if users prefer large volumes. A squared term of lot size (TON^2) was included to allow for its marginal effect to be increasing or decreasing. Small square bales were expected to receive a premium over large bales because of user convenience. Specifying small square bales as the base bale type, binary variables for large square bales (*LSB*) and large round bales (*LRB*) were expected to have negative coefficients. Because square bales are easier to transport than round bales, the discount associated with *LSB* was predicted to be smaller than that with *LRB*. Some users, however, depending on their feeding system, might prefer round bales.

Inspection of the data revealed that average prices in 1996/1997 and 1997/1998 marketing years were higher than the remaining years because of reduced production. The Wisconsin Agricultural Statistics Service reported approximately 9% less production in those 2 years than the average of the 3 subsequent years. Thus, a dummy variable was used in each model to account for the difference in the average prices during these 2 years (*D9697*).

Model A was specified as follows:

$$(1)\quad P_i = a_0 + a_1S1_i + a_2S2_i + a_3S3_i + a_4S4_i + a_5S5_i + a_6TON_i + a_7TON_i^2 + a_8LRB_i + a_9LSB_i + a_{10}D9697_i + e_{a,i},$$

where i is an index for lot; *S1* through *S5* are binary variables that correspond to *RFV* quality Standards 1–5; $a_0, \ldots, a_{10}$ are coefficients; and e_a is an error term. Relative to Prime, all quality standards were expected to be discounted. Hence, *S1, S2, . . . , S5* should have negative coefficients, increasing in absolute magnitude with lower quality standards.

Similarly in Model B, Prime was used as the base quality standard for the individual nutritional factors, *CP*, *ADF*, and *NDF*. The model was specified as

$$(2)\quad P_i = b_0 + b_1CP1_i + b_2CP2_i + b_3CP3_i + b_4CP4_i + b_5CP5_i + b_6ADF1_i + b_7ADF2_i + b_8ADF3_i + b_9ADF4_i + b_{10}ADF5_i + b_{11}NDF1_i + b_{12}NDF2_i + b_{13}NDF3_i + b_{14}NDF4_i + b_{15}NDF5_i + b_{16}TON_i + b_{17}TON_i^2 + b_{18}LRB_i + b_{19}LSB_i + b_{20}D9697_i + e_{b,i},$$

where *CP1* through *CP5*, *ADF1* through *ADF5*, and *NDF1* through *NDF5* are binary variables that correspond to quality Standards 1–5 for *CP*, *ADF*, and *NDF*, respectively; $b_0, \ldots, b_{20}$ are coefficients, and e_b is an error term. Because standards are determined so that higher quality corresponds to greater *CP* percentages and lesser *ADF* and *NDF* percentages, all quality-standard dummies were expected to have negative coefficients, with increasing magnitude in absolute value as quality declined.

Model C relates the price to values of individual nutritional factors and was specified as

$$(3)\quad P_i = c_0 + c_1CP_i + c_2ADF_i + c_3NDF_i + c_4TON_i + c_5TON_i^2 + c_6LRB_i + c_7LSB_i + c_8D9697_i + e_{c,i},$$

where *CP*, *ADF*, and *NDF* are percentages of crude protein, acid detergent fiber, and neutral detergent fiber, respectively; $c_0, \ldots, c_8$ are coefficients; and e_c is an error term. *CP* was expected to have a positive impact on alfalfa price, assuming buyers paid a premium for greater percentages of crude protein. *ADF* and *NDF* were expected to have negative coefficients, because larger values of *ADF* and *NDF* are associated with poorer quality hay.

Choice of functional form can have important effects on the results. Thus, we specified Model D by applying the Box-Cox transformation to the nonbinary variables in Model C:

$$(4) \quad (P_i^\lambda - 1)/\lambda = d_0 + d_1(CP_i^\lambda - 1)/\lambda + d_2(ADF_i^\lambda - 1)/\lambda + d_3(NDF_i^\lambda - 1)/\lambda + d_4(TON_i^\lambda - 1)/\lambda + d_5(TON_i^{2\lambda} - 1)/\lambda + d_6LRB_i + d_7LSB_i + d_8D9697_i + e_{d,i},$$

where *CP*, *ADF*, and *NDF* are percentages of crude protein, acid detergent fiber, and neutral detergent fiber, respectively; λ is the parameter of the Box-Cox transformation; $d_0, \ldots, d_8$ are coefficients; and e_d is an error term. The Box-Cox model encompasses the two common specifications used in empirical analysis: $\lambda = 1$ implies a linear functional form (Model C), and $\lambda = 0$ implies a log-linear functional form. Similar to Model C, *CP* was expected to have a positive impact on alfalfa price, and *ADF* and *NDF* were expected to have negative influences because larger values of *CP* and smaller values of *ADF* and *NDF* are associated with higher quality hay.

All models were estimated by nonlinear ordinary least squares using 1996/1997 through 1999/2000 data and were tested for heteroscedasticity and nonnormality in errors. Observations from the 2000/2001 marketing season were reserved for model validation. On the basis of both the White and Breusch-Pagan tests, the null hypothesis of homoscedastic errors was rejected for all models at the 5% significance level. Because the form of heteroscedasticity was unknown, the models were re-estimated using generalized method-of-moments (GMM) estimator. According to the Shapiro-Wilk *W* test, the null hypothesis of normality of errors could not be rejected for all models at the 5% significance level. Then, models were evaluated for in-sample and out-of-sample predictability. Finally, alternative pricing models (A, B, C, and D) were compared through predicted prices for lots of alfalfa classified into each quality standard by *CP* and *RFV* percentages.

Results

Estimation Results

Estimation results using GMM are presented in Table 3. In all models, all coefficients have hypothesized signs, and most were statistically significant at the 5% level, supporting a relationship between alfalfa price and quality attributes. Models were similar in adjusted R^2 values. In years 1996/1997 and 1997/1998, the average price was estimated to be higher than the rest of the sample period by \$61–\$64 per ton.

Lot size (*TON*) was statistically significant in Model D and insignificant in Models A–C. Squared lot size (TON^2) was significant in Models C and D. The signs consistently suggest that premiums were paid for larger volumes of alfalfa at a decreasing rate. The marginal effect of tonnage evaluated at sample averages indicate that premiums paid ranged from \$0.24 (Model D) to \$0.92 (Model C) per ton.

Estimated discounts associated with bale types were also consistent across models. The marginal effects for Models A, B, and C were computed by subtracting the price of the two bale types ($LRB = 1$ and $LSB = 1$, respectively) from the base price ($LRB = LSB = 0$), holding other variables at sample means. All models indicated that buyers paid a premium for alfalfa baled in small square bales. The discount for large square bales ranged from \$2.01 (Model D) to \$2.23 (Model C) per ton, but it was not statistically significant. Historically, the difference in prices paid for small and large square bales has been controversial; Ward (1994) reported a greater discount of \$7.51 to \$10.17 per ton with 1992 and 1993 data, which contradicted some of his earlier findings that a premium was paid for large square bales over small square bales (e.g., Ward 1987). The results suggest that buyers of large round bales, on average, paid a discount of $16 per ton,[4] which is comparable to Ward's (1987) findings of $11.70–$19.65 per ton in 1983–1986 and $16.43–$26.83 per ton in 1992–1993 (Ward 1994). These price differences should be considered when selecting optimal baling equipment for producers, along with costs of different balers, which depend on alfalfa acreage (Taylor). For example, Taylor found that baling costs for small square bales were comparable with those of large round bales and about half the costs of large square bales for 500 acres, but for acreages greater than 1,500, baling costs of small square bales exceeded those of other bale types.

According to Model A, buyers received significant discounts for poorer quality alfalfa rated according to *RFV*. Buyers paid an average of $11.15 less per ton for alfalfa with *RFV* of Standard 1 than for Prime alfalfa. Discounts paid for lower *RFV* standards did not increase linearly with standards. Relative to Prime, alfalfa of Standard 2 was discounted approximately twice as much as Standard 1. Alfalfa with *RFV* value less than 75 (Standard 5) was sold for an average of $72.45 less per ton than those with *RFV* greater than 151 (Standard Prime). According to the pricing system that relies on *RFV* standards, producers should produce alfalfa with at least *RFV* of 125 (Standard 1) to avoid increasingly larger discounts. As noted by Blank, Orloff, and Putnam, however, additional yield may offset the price discounts associated with lower quality grades. An optimal alfalfa cutting schedule should account for the yield-quality tradeoff in addition to price-quality relationships discussed here.

Results for Model B illustrate the degree of discounts associated with lesser amounts of *CP* and greater amounts of *ADF* and *NDF*. The market did not respond to variations in the *CP* standard for *CP* greater than 17% (Standard 1 and Prime). When the *CP* percentage was between 14% and 16% (Standard 2), alfalfa was discounted by an average of $6.34 per ton relative to the price for *CP* values greater than 19% (Prime). The discount did not increase drastically for *CP* percentages between 8 and 16, but below 8% (Standard 5) the discount more than tripled to $31.35. The discounts for *ADF* were similar for the lowest three standards, (i.e., for *ADF* percentages greater than 40, Standards 3–5). The discount for *ADF* Standard 1 relative to Prime was more than $9 per ton, which was the greatest discount for Standard 1 among the nutritional factors considered. The market did not respond when the *NDF* standard varied between Prime and Standard 1. However, there were discounts for *NDF* ratings less than Standard 1.

The results for Model C indicate marginal values for the individual nutritional factors. A 1% increase in *CP* brought an average premium of $0.83 per ton. This is comparable with a previously reported range of $0.87–$3.24 per ton for *CP* impacts (Klemme, Chavas, and Moriarty; Ward 1987, 1994). *ADF* had the greatest impact on price, where a 1% increase in *ADF* discounted alfalfa by an average of $2.19 per ton. A 1% increase in *NDF* reduced the average price by $1.01 per ton. Ward (1994) reported similar effects of *ADF* and *NDF* of about $1.63 per ton.

For Model D with the Box-Cox transformation, the marginal effects were computed from the estimated parameters.[5] At the sample

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[4] The marginal effect of large round bales relative to small square bales, according to Model D, was $16.13.

[5] Marginal effects for Model D were computed for independent variables (X = *CP*, *ADF*, and *NDF*) as $\partial P/\partial X = \delta(\bar{X}/\bar{P})^{\lambda-1}$, where P is price per ton, upper bars denote sample means of the variables, δ is the estimated coefficient for the corresponding variables, and λ is the estimated parameter for Box-Cox transformation. Similarly, the marginal effects for lot size (*TON*) and bale type (B = *LRB* and *LSB*) were computed as

$$\frac{\partial P}{\partial TON} = \bar{P}^{1-\lambda}(\delta_4 \overline{TON}^{\lambda-1} + 2\delta_5 \overline{TON}^{2\lambda-1}),$$

and

$$\frac{\partial P}{\partial B} = \delta^{(1-\lambda)/\lambda},$$

where δ_4 and δ_5 are estimates of the coefficients d_4 and d_5 in Equation (4).

Table 3. Estimation Results from Wisconsin Alfalfa Hay Auction Data (1,003 observations), 1996/1997 to 1999/2000[a]

Regressors[b]	Model A	Model B	Model C	Model D $\lambda = 0.37^*$ (0.12)
Intercept	81.82*	85.58*	168.26*	23.15*
	(3.53)	(3.47)	(12.61)	(7.91)
S1	−11.15*	—	—	—
	(2.52)			
S2	−26.87*	—	—	—
	(2.75)			
S3	−46.50*	—	—	—
	(3.17)			
S4	−55.98*	—	—	—
	(4.03)			
S5	−72.45*	—	—	—
	(8.79)			
CP	—	—	0.83*	0.23*
			(0.27)	(0.11)
CP1	—	−0.43	—	—
		(1.76)		
CP2	—	−6.34*	—	—
		(1.90)		
CP3	—	−8.16*	—	—
		(2.96)		
CP4	—	−10.17*	—	—
		(3.80)		
CP5	—	−31.35*	—	—
		(7.76)		
ADF	—	—	−2.19*	−1.06*
			(0.31)	(0.24)
ADF1	—	−9.25*	—	—
		(2.90)		
ADF2	—	−18.59*	—	—
		(3.34)		
ADF3	—	−30.20*	—	—
		(4.45)		
ADF4	—	−31.49*	—	—
		(5.36)		
ADF5	—	−33.10*	—	—
		(4.69)		
NDF	—	—	−1.01*	−0.84*
			(0.20)	(0.16)
NDF1	—	−2.63	—	—
		(2.67)		
NDF2	—	−11.92*	—	—
		(3.11)		
NDF3	—	−18.88*	—	—
		(4.07)		
NDF4	—	−13.76	—	—
		(6.86)		

Table 3. Continued

Regressors[b]	Model A	Model B	Model C	Model D $\lambda = 0.37*$ (0.12)
NDF5	—	−30.21*	—	—
		(7.53)		
TON	0.44	0.74	1.02	0.50*
	(0.70)	(0.69)	(0.67)	(0.23)
TON^2	−0.02	−0.04	−0.05*	−0.12*
	(0.03)	(0.03)	(0.03)	(0.06)
LRB	−15.96*	−16.09*	−15.90*	−1.07*
	(2.71)	(2.41)	(2.60)	(0.59)
LSB	−2.06	−2.05	−2.23	−0.13
	(1.73)	(1.64)	(1.62)	(0.13)
D9697	61.76*	63.37*	63.51*	3.80*
	(1.72)	(1.64)	(1.63)	(2.04)
R^2	0.725	0.750	0.750	0.759[d]
Adjusted R^2	0.722	0.744	0.748	0.757[d]
RMSE[c] 96/97–99/00	19.740	19.072	18.807	18.464
RMSE[c] 00/01	18.777	19.066	18.754	17.752

[a] The dependent variable in all models is alfalfa price per ton. Values in parentheses are standard errors.
[b] *S1–S5, CP1–CP5, ADF1–ADF5,* and *NDF1–NDF5* are binary variables that correspond to quality standards 1–5 for relative feed value, crude protein, acid detergent fiber, and neutral detergent fiber, respectively. *CP, ADF,* and *NDF* are crude protein, acid detergent fiber, and neutral detergent fiber percentages, respectively. *TON* is lot size in tons, *LRB* and *LSB* are binary variables for large round bales and large square bales, respectively, and *D9697* equals 1 for observations from the 1996/1997 and 1997/1998 alfalfa hay marketing seasons.
[c] Root mean square error.
[d] R^2 for Model D, which is nonlinear, is not directly comparable to R^2 for Models A, B, and C, which are linear.
* Significant at the 5% level.

mean, a percentage increase in *CP* increased the price by $0.63 per ton, whereas percentage increases in *ADF* and *NDF* decreased the price by $1.82 and $1.23 per ton, respectively. Consistent with results from Models B and C, the results suggest that *ADF* percentages had the largest marginal impact on price.

The estimated models were used to predict alfalfa auction prices, and root mean square errors (RMSE) were computed for the period used in estimation and *ex post* for the 2000–2001 marketing season (Table 3). All models were similar in predictability. Model D, with the smallest in-sample RMSE, predicted the 2000–2001 prices with greater accuracy than Models A, B, and C.

Price Prediction when Differences in RFV and CP Classifications Are Considered

A comparison of prices received for lots with varying levels of *RFV* and *CP* underscores the impacts of these two important quality factors on alfalfa prices and the differences across the pricing models. In our entire sample, *RFV* and *CP* had a correlation of 0.647, indicating that one characteristic did not necessarily reflect the other. Therefore, we sorted the observations by *CP* standards, and within each *CP* standard we sorted by *RFV* standards. Because differences between in-sample and out-of-sample RMSEs were small (Table 3), we used all 5 years of data. In Table 4, partitions correspond to *CP* standards, and columns within each partition correspond to *RFV* standards. Rows report means, coefficients of variation (CV), mean error (ME), and RMSE of price predictions for sorted observations presented per model. ME was calculated as an average of estimated price minus actual price per ton in each quality standard. ME indicates any systematic bias, whereas RMSE allows us to compare goodness of fit (Pindyck and Rubinfeld).

Table 4. Average Price Predictions ($/ton) when Differences in *RFV* and *CP* Classifications Are Considered[a]

	CP Quality Standard Prime (434 Observations)					
RFV Standard	Prime	1	2	3	4	5
No. of Observations	122	217	81	13	1	—
Actual						
Mean	98.64	85.73	76.48	61.73	40.00	—
CV (%)	39	36	43	31	—	—
Model A						
Mean	98.80	83.23	70.25	48.44	25.78	—
CV (%)	28	30	39	53	—	—
ME	0.16	−2.50	−6.23	−13.29	−14.22	—
RMSE	18.82	17.71	22.06	18.45	14.22	—
Model B						
Mean	102.16	88.70	77.16	57.31	35.08	—
CV (%)	29	29	36	51	—	—
ME	3.51	2.97	0.68	−4.42	−4.92	—
RMSE	18.69	17.17	20.07	15.99	4.92	—
Model C						
Mean	102.57	84.78	73.80	54.60	29.40	—
CV (%)	29	30	38	49	—	—
ME	3.93	−0.95	−2.68	−7.13	−10.60	—
RMSE	18.48	16.89	20.23	15.30	10.60	—
Model D						
Mean	103.10	82.76	72.86	57.69	39.54	—
CV (%)	35	33	37	40	—	—
ME	4.45	−2.98	−3.62	−4.04	−0.46	—
RMSE	18.38	17.09	20.49	12.15	0.46	—

Notes: Number of Observations is total number of Crude Protein (*CP*) observations in each quality standard classified by Relative Feed Value (*RFV*); Mean is average actual or predicted price; CV is coefficient of variation; ME is mean error; RMSE is root mean square error; Model specification, Model A is *RFV* Standards; Model B is standards of *CP*, *ADF*, and *NDF*; Model C is actual values of *CP*, *ADF*, and *NDF*; and Model D is Box-Cox transformation of actual values of *CP*, *ADF*, and *NDF*.

[a] When the number of observations was four or less, coefficient of variation was not calculated.

Clearly, hay with more protein will not necessarily have a better *RFV* rating. For example, consider the 434 observations classified as Prime according to *CP* percentages. Of these 434 observations, only 122 observations (28%) were also Prime according to *RFV* standards. The average price received for these 122 observations at the auctions was $98.64 per ton. The average of predicted prices for these 122 lots using Model A, the system based on *RFV*, was $98.80 per ton, very close to the actual price. When standards of *CP*, *ADF*, and *NDF* were individually taken into account (Model B), the average predicted price was higher for these 122 observations at $102.16 per ton. When price was determined by numerical values of *CP*, *ADF*, and *NDF* (Models C and D), the price reflected greater *CP* percentages in our example, and the average of predicted prices increased to a range between $102.57 and $103.10 per ton, 4%–5% higher than the actual average price. This suggests that models based on numerical values of quality characteristics overvalue greater amounts of *CP* in hay that is Prime according to *RFV* standards.

Table 4. (Extended)

CP Quality Standard 1 (324 Observations)						*CP* Quality Standard 2 (342 Observations)					
Prime	1	2	3	4	5	Prime	1	2	3	4	5
29	141	136	18	—	—	7	91	163	70	9	2
87.07	91.42	83.96	83.33	—	—	96.43	99.92	86.63	65.25	47.78	50.00
49	42	42	37	—	—	60	42	42	50	53	—
95.16	92.29	79.97	73.89	—	—	98.20	104.85	88.17	65.86	45.28	40.84
27	32	39	48	—	—	33	30	36	50	73	—
8.09	0.87	−3.99	−9.45	—	—	1.77	4.93	1.80	0.60	−2.50	−9.16
25.59	17.87	18.49	21.08	—	—	25.67	20.30	20.69	21.07	17.10	23.73
95.88	95.79	86.10	85.69	—	—	91.96	102.81	87.92	70.97	53.49	50.00
29	32	39	46	—	—	37	31	37	46	68	—
8.81	4.37	2.14	2.35	—	—	−4.47	2.89	1.56	5.72	5.72	−0.61
24.93	17.95	17.16	21.59	—	—	25.32	20.12	20.41	21.54	19.06	22.68
94.14	90.18	80.75	79.50	—	—	93.71	100.09	86.84	69.19	44.83	46.83
30	34	41	48	—	—	36	32	37	49	83	—
7.07	−1.24	−3.22	−3.83	—	—	−2.72	0.17	0.48	3.94	−2.94	−3.17
23.54	17.81	17.93	21.35	—	—	25.17	18.96	19.79	21.97	20.00	22.17
94.40	89.75	80.84	81.14	—	—	94.49	100.42	86.62	71.49	52.87	55.27
35	36	39	39	—	—	40	33	36	39	53	—
7.33	−1.67	−3.13	−2.19	—	—	−1.93	0.50	0.25	6.23	5.09	5.27
21.49	17.70	17.59	18.10	—	—	22.02	18.23	19.44	20.84	14.58	14.31

When *CP* and *RFV* ratings were both Standard 2 or higher, all four models generally predicted the price of hay relatively well, with small ME and RMSE, especially when *CP* and *RFV* were both at the same quality standard. For hay with greater *CP* (Prime or Standard 1) and *RFV* less than Standard 1, Models B, C, and D, which consider all nutrients, generally predicted more accurately than Model A, which relied only on *RFV*. For hay with less *CP* (Standards 3 and 4), all models tended to underestimate price if *RFV* was ranked equal to or lower than its *CP* standard (i.e., Standards 3–4 and 4–5) and to overestimate otherwise, as expected from the industry's reliance on *RFV*. If hay was ranked as Standard 5 according to *CP*, no model could reliably predict its price because there were limited numbers of observations. Our results were consistent with those of Klemme, Chavas, and Moriarty, who noted that relationships between quality characteristics and hay price were stronger with high-quality hay. We add the observation that, on the average, pricing models tended to predict more accurately when *CP* and *RFV* were of similar quality standards.

Based on CV in Table 4, CV of predicted hay prices within the same *CP* standard generally increased as *RFV* standard declined. Variability in actual prices for hay with *RFV* standard higher than or equal to Standard 2 (i.e., Prime and Standards 1–2) was larger than variability in predicted prices, whereas pre-

Table 4. (Continued)

	CP Quality Standard 3 (121 Observations)					
RFV Standard	Prime	1	2	3	4	5
No. of Observations	1	6	55	49	8	2
Actual						
Mean	80.00	93.33	86.55	67.58	50.25	45.00
CV (%)	—	53	42	49	68	—
Model A						
Mean	83.84	112.68	92.37	63.37	45.93	64.55
CV (%)	—	28	34	49	79	—
ME	3.84	19.35	5.83	−4.21	−4.32	19.55
RMSE	3.84	37.31	19.28	19.93	7.05	19.84
Model B						
Mean	71.76	108.20	87.89	65.91	48.15	71.86
CV (%)	—	33	36	49	76	—
ME	−8.24	14.87	1.34	−1.67	−2.10	26.86
RMSE	8.24	35.29	17.77	19.46	8.15	27.11
Model C						
Mean	76.99	105.10	86.47	64.49	42.31	68.97
CV (%)	—	32	37	49	85	—
ME	−3.01	11.77	−0.07	−3.07	−7.94	23.97
RMSE	3.01	33.09	16.96	19.68	10.44	24.59
Model D						
Mean	74.51	106.26	86.51	66.67	51.65	69.15
CV (%)	—	30	34	39	53	—
ME	−5.49	12.93	−0.03	−0.91	−1.40	24.15
RMSE	5.49	32.86	17.17	18.67	8.83	24.56

dicted price variability for hay with lower *RFV* standards was often larger than actual.

Implications

Hence, we draw these implications for alternative alfalfa pricing systems. For high-quality hay with similar quality standards of *RFV* and *CP*, a pricing system based on the *RFV* standards (Model A) usually reflected the market value well. However, such a pricing system tended to overprice (underprice) hay when its *RFV* standard was greater (less) than its *CP* standard. A pricing system that incorporated standards of *CP*, *ADF*, and *NDF* separately (Model B) performed similarly to the former pricing system, but its margin of error tended to be smaller for higher quality hay, and its direction of bias was not as systematic as the system based on *RFV* standards. A pricing system that accounted for specific amounts of these nutrients (Models C or D) tended to perform better than the *RFV* pricing system (Model A) for hay with higher *CP* standards (Prime or Standard 1).

For dairy farmers seeking greater milk production, energy is usually the limiting factor, and more feed intake is important in achieving greater energy. In general, less fiber is associated with greater energy. *CP* is not as important as fiber content because *CP* does not limit feed intake. Moreover, *CP* of 19% is adequate for most dairy rations, and more *CP* does not significantly enhance milk production, because extra protein degrades rapidly and is lost (Rankin; Ward, Huhnke, and Cuperus). *RFV* provides an aggregate measure of digestible dry matter and dry-matter intake

Table 4. (Continued Extended)

CP Quality Standard 4 (42 Observations)						*CP* Quality Standard 5 (6 Observations)					
Prime	1	2	3	4	5	Prime	1	2	3	4	5
—	—	7	21	11	3	—	—	—	2	4	—
—	—	87.14	77.98	74.18	38.33	—	—	—	66.55	53.16	—
—	—	43	34	48	—	—	—	—	—	—	—
—	—	100.26	79.77	69.21	31.41	—	—	—	66.23	69.25	—
—	—	30	35	44	—	—	—	—	—	—	—
—	—	13.12	1.80	−4.98	−6.93	—	—	—	−0.20	15.57	—
—	—	18.00	14.66	19.54	14.82	—	—	—	18.42	26.39	—
—	—	93.55	82.26	71.28	41.20	—	—	—	49.22	43.97	—
—	—	35	37	48	—	—	—	—	—	—	—
—	—	6.41	4.28	−2.90	2.86	—	—	—	−17.03	−9.19	—
—	—	13.58	16.24	16.64	21.45	—	—	—	25.59	27.44	—
—	—	91.54	78.84	63.12	30.63	—	—	—	59.83	53.34	—
—	—	36	36	55	—	—	—	—	—	—	—
—	—	4.40	0.76	11.06	−7.71	—	—	—	−6.42	0.18	—
—	—	11.10	13.65	20.26	16.85	—	—	—	18.44	22.54	—
—	—	90.82	78.17	67.20	44.70	—	—	—	61.86	58.31	—
—	—	33	30	37	—	—	—	—	—	—	—
—	—	3.68	0.19	−6.98	6.37	—	—	—	−4.39	5.14	—
—	—	11.80	12.25	19.63	9.48	—	—	—	11.61	17.41	—

(see footnote 1), which are important to dairy farmers seeking a high-energy ration to achieve greater milk production per cow. Therefore, it is not surprising that, in the aggregate, the model based on *RFV* was about as accurate as the other pricing models, because it focuses on the nutritional issue that tends to be the most limiting factor in dairy rations. Despite the statistical evidence that other nutritional factors are valuable, our aggregate analysis indicates that *RFV* performs well as a criterion for pricing alfalfa hay in a market in which the majority of alfalfa purchased is fed to dairy cows.

On the other hand, predicted prices diverged more from actual prices on average as the difference between *RFV* quality rating and *CP* quality rating increased. Also, at a given *CP* quality standard, the variability of price projections increased as the *RFV* standard decreased. These results indicate that alfalfa price reflects both *RFV* and *CP* standards. Moreover, any aggregation results in a loss of information. The *RFV* index assumes a fixed relationship between *ADF* and *NDF*, which had a correlation of 0.861 in our entire sample. If users of alfalfa decide to place an emphasis on one of the fibers, pricing of alfalfa should not rely on an aggregated index such as *RFV*.

Values of Quality in Shorter Supply and Larger Supply Years

Values of quality factors in shorter supply years were compared with those in years with larger supply. In years in which alfalfa supply was shorter, we hypothesized that quality characteristics would not have as large of an impact on price as they would when alfalfa supply was larger, because buyers would likely prioritize securing an adequate quantity of hay over its quality. To examine this hypothesis, the discounts and premiums paid in the marketing years 1996/1997 and 1997/1998 (505 observations), when supply was shorter, were estimated separately from those in years 1998/1999 and 1999/2000 (498 observations).[6] The discounts paid for lower standards of *RFV* in years with shorter supply were smaller, as expected, but exhibited similar patterns as those in years having larger supply. For instance, the percentage discounts for alfalfa in *RFV* Standard 2 were 24.60% and 25.86% of the Prime price in the years with larger and shorter supply, respectively. The same held true for *ADF* and *NDF* in Model B, indicating that when alfalfa supply was shorter, there was no change in relative discounts for lower quality standards measured by fiber content. However, in Model C when the values of quality characteristics were used, larger values of *ADF* and *NDF* received much smaller discounts in shorter supply years. Moreover, in shorter supply years lesser amounts of *CP* were not discounted as much as in years of larger supply. For example, discounts for Standards 1–5, relative to the Prime, in the years with shorter supply ranged from 0.78% to 11.81%, whereas the percentage discounts ranged from 3.66% to 22.57% in the years with larger supply. This is consistent with substitutability of nutrients. Few substitutes exist for alfalfa as a *CP* source (Bolsen), but substitutes for fiber content are more readily available.

Concluding Remarks

Although alfalfa is valued for its mixture of nutritional characteristics, in recent years the aggregate index *RFV* has been used to establish hay prices throughout the Midwest (Moore, Burnes, and Fisher). This has raised concern about how well *RFV* signals the values of other nutritional qualities to market participants. In this paper, a price-quality relationship was analyzed by using sale data at two auction locations in Wisconsin during the 1996/1997 through 2000/2001 marketing years. Our results confirmed findings of previous studies that premiums were paid for additional *CP* percentages and *RFV* values and that discounts were deducted for additional percentages of *ADF* and *NDF*.

Similar R^2 values for alternative regression models and similar RMSEs of price predictions based on the regression models suggested that an aggregate *RFV* index that did not consider *CP* content adequately priced alfalfa. Individual quality characteristics were, however, significant in all four models. When we disaggregated price predictions by both *RFV* and *CP* standards, we found that accuracy of price predictions depended on both of these quality characteristics. All of our pricing models predicted well on average for high-quality hay when the quality standards for *RFV* and *CP* were ranked similarly. However, the models did not predict well for poorer quality hay, and the accuracy of predictions decreased as the differences in *RFV* and *CP* standards increased. In particular, the pricing model using *RFV* quality standards on average underpriced hay when quality based on *RFV* relative to quality based on *CP* was low, and it overpriced hay when quality based on *RFV* relative to quality based on *CP* was high.

A major contribution of this study was the disaggregation of price predictions from the alfalfa pricing models to account for differences in *RFV* and *CP* quality levels. This disaggregate analysis confirmed that both *RFV* and *CP* were important determinants of alfalfa hay price, as indicated by the significance of *RFV* and *CP* quality variables, even though R^2 and RMSE did not differ much among models. The disaggregate analysis also revealed that the model based on *RFV* quality standards exhibited systematic bias in price predictions. In addition, comparing quality effects in years of shorter and larger supply revealed that *CP* percentages were valued more when supply was scarce. Individual values of *ADF* and *NDF*

[6] Complete results for the analysis of the years in shorter supply and larger supply are available from the authors.

were discounted less in shorter supply years, but discounts for standards of fiber content remained unchanged.

Our results provide evidence that a pricing model that used nutritional values directly was a more accurate predictor of out-of-sample prices on average than those that relied on quality standards derived from nutritional values. The different pricing models were similar, however, in the amount of price variability they explained and in aggregate predictability. Crude protein, not accounted for by *RFV*, and *ADF* and *NDF*, both used to calculate *RFV*, were significant in the pricing models. Therefore, it is tempting to suggest an alternative index to *RFV* that incorporates additional individual nutritional values. A new index has recently been proposed called relative feed quality (RFQ; Undersander and Moore). The new RFQ formulation includes total digestible nutrients, which take into account *CP* values. In comparing our results with previous studies, it is clear that specific premiums and discounts associated with various nutritional factors differ across markets and time periods. That is, such an index would need to be specified for individual marketplaces and be constantly updated.

In conclusion, there is evidence that reliance on an aggregate quality indicator such as *RFV* may undervalue *CP* percentages. An aggregate pricing index may work well for high-quality hay having *RFV* and *CP* with similar quality ratings, but it does not work as well for poorer quality hay or for hay with *RFV* and *CP* at widely different quality ratings. Buyers of alfalfa hay need information on both *CP* and *RFV*. Therefore, aggregation of *CP* and *RFV* into a single quality index is not warranted.

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References

Blank, S.C., S.B. Orloff, and D.H. Putnam. "Sequential Stochastic Production Decisions for a Perennial Crop: The Yield/Quality Tradeoff for Alfalfa Hay." *Journal of Agricultural and Resource Economics* 26(July 2001):195–211.

Bolsen, K. Personal Communication. Professor, Department of Animal Science and Industry, Kansas State University, March 2002.

Breusch, T.S., and A.R. Pagan. "A Simple Test for Heteroscedasticity and Random Coefficient Variation." *Econometrica* 47(September 1979): 1287–94.

Cherney, J., and M. Hall. "Putting Forage Quality in Perspective." *PSU Forage.* Penn State University, August 1997. Internet site: http://www.cas.psu.edu/docs/casdept/agronomy/forage/docs/quality/perspective.html (Accessed May 2001).

Gray, A.M., and M. Hill. "Returns for Hay Marketed on Relative Feed Value Depended on Analytical Procedure." *Journal of Natural Resources and Life Science Education* 23(Fall 1994):109–12.

Griliches, Z., ed. *Price Indexes and Quality Change.* Cambridge, MA: Harvard University Press, 1971.

Grisley, B., S.E. Stefanou, and T. Dickerson. "Factors Affecting the Price of Hay at a Pennsylvania Auction." *Northeastern Journal of Agricultural and Resource Economics* 14(April 1985):48–56.

Hoffman, P.C., R.D. Shaver, D.K. Combs, D.J. Undersander, L.M. Bauman, and T.K. Seeger. "Understanding *NDF* Digestibility." *Focus on Forage,* Volume 3, No. 10. University of Wisconsin Extension. Internet site: http://www.uwex.eduy/ces/crops/uwforage/NDFDig.html (Accessed October 2001).

Klemme, R., J.P. Chavas, and J. Moriarty. "A Hedonic Analysis of Wisconsin Hay Auction Prices, 1983–1986." Paper presented at the AAEA Annual Meeting, Knoxville, TN, July 1988.

Lacefield, G.D. "Alfalfa Hay Quality Makes the Difference." University of Kentucky Department of Agronomy AGR-137, Lexington, KY, July 1988.

Ladd, G.W., and M.B. Martin. "Prices and Demand for Input Characteristics." *American Journal of Agricultural Economics* 58(February 1976):21–30.

Ladd, G.W., and V. Suvannunt. "A Model of Consumer Goods Characteristics." *American Journal of Agricultural Economics* 58(August 1976):504–10.

Lancaster, K.J. "A New Approach to Consumer Theory." *Journal of Political Economy* 74(April 1966):132–56.

Moore, J.E., J.C. Burnes, and D.S. Fisher. "Multiple Regression Equation for Predicting Relative Feed Value of Grass Hays." *TEKTRAN.* U.S.

Department of Agriculture, Agricultural Research Service. Internet site: www.nalusda.gov/ttic/tektran/data/000007/32/0000073238.html (Accessed July 2001).

National Agricultural Statistics Service, U.S. Department of Agriculture. *Historical Track Records.* Internet site: http://www.usda.gov/nass/pubs/histdata.htm (Accessed May 2001).

North American Alfalfa Improvement Conference. "Importance of Alfalfa." North American Alfalfa Improvement Conference, February 2000. Internet site: http://www.naaic.org/Alfalfa/Importance.html (Accessed July 2001).

Pindyck, R.S., and D.L. Rubinfeld. *Econometric Models and Economic Forecasts,* 4th ed. Boston: Irwin McGraw-Hill, 1998.

Rankin, M. Personal Communication. Crops and Soils Agent, University of Wisconsin Extension, Fond du Lac County, March 2002.

Rosen, S. "Hedonic Prices and Implicit Markets: Production Differentiation in Pure Competition." *Journal of Political Economy* 82(January/February 1974):34–35.

Shapiro, S.S., and M.B. Wilk. "An Analysis of Variance Test for Normality (Complete Samples)." *Biometrika* 52(December 1965):591–611.

Taylor, R.K. "Harvest Equipment and Storage." *Alfalfa Production Handbook.* Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Manhattan, KS, October 1998.

Undersander, D., and J.E. Moore. "Relative Forage Quality." Internet site: www.uwex.edu/ces/crops/uwforage/RFQvs*RFV*.htm (Accessed April 2003).

Ward, C.E. "Buyer Preferences for Alfalfa Hay Attributes." *North Central Journal of Agricultural Economics* 9(July 1987):289–96.

———. "Price and Quality Relationships for Alfalfa Hay." *Journal of the American Society of Farm Managers and Rural Appraisers* 58(June 1994):130–34.

Ward, C.E., R.L. Huhnke, and G.W. Cuperus. "Alfalfa Preferences by Oklahoma and Texas Dairy Producers." Oklahoma State University, Extension Circular E-936, Stillwater, OK, 1995.

Ward, C.E., S. Kariuki, and R.L. Huhnke. "Alfalfa Buyer Preferences." *Domestic and International Markets for Alfalfa Hay.* Oklahoma State University, Final Report on Marketing Oklahoma Hay to United States and International Markets, Stillwater, OK, January 1998.

White, H. "A Heteroscedasticity-consistent Covariance Matrix Estimator and a Direct Test for Heteroscedasticity." *Econometrica* 48(May 1980):817–38.

Wisconsin Agricultural Statistics Service. Internet site: http://nass.usda.gov:81/ipedb/report.html (Accessed December 2001).