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RESEARCH ARTICLE

Analyzing US Alfalfa Hay Market Dynamics: Effects of Quality Grade on Premiums and Discounts

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Abstract
This study analyzes empirically and graphically the effects of the relative market price level on the premiums and discounts received associated with alfalfa hay quality. Findings indicate that at times when alfalfa prices are elevated relative to the average, there is no significant impact on the average premiums and discounts received. Conversely, at times when alfalfa prices are depressed relative to the average, there are statistically significant variations in the premiums and discounts across quality grades compared with a market characterized by average prices. Understanding these dynamics can aid producers in optimizing production decisions and assist consumers in managing input costs.

Keywords: Hay pricing; hay market strength; hay quality premium variability

JEL Classifications: Q10; Q11; Q13

1. Introduction

Alfalfa hay is a significant agricultural commodity in the United States, ranking as the fourth most produced crop by volume (NAAIC, 2017). In 2024, US production reached approximately 54 million tons, cultivated on an estimated 15.6 million acres (USDA NASS, 2024c; USDA NASS, 2024a). The United States Department of Agriculture (USDA) valued national alfalfa hay production at $10.57 billion in 2023 (USDA NASS, 2024d), highlighting the economic importance of this crop. The economic value an alfalfa hay producer receives for their output is often considered a function of its quality attributes (Hopper et al., 2004; Peake et al., 2019; Rudstrom, 2004). These quality attributes are non-homogeneous, setting the alfalfa hay market apart from staple commodity crops such as corn and wheat. In 2003, the USDA established standards to facilitate a consistent grading of alfalfa hay according to various quality attributes (Rankin, 2016). Through adhering to these grading standards, market participants can more easily assess and compare the quality of alfalfa hay, aiding in the price discovery process. The USDA grading system categorizes hay into one of five quality grades: utility, fair, good, premium, and supreme. To qualify for a quality grade, the hay must meet established benchmarks within several measurable hay quality metrics associated with livestock feed digestibility. These metrics include acid detergent fiber (ADF), neutral detergent fiber (NDF), total digestible nutrients (TDN), crude protein (CP), and relative feed value (RFV) as outlined in Table 1 (USDA AMS, n.d.a). ADF is one measure of the digestibility of a hay sample and is an essential component in the calculation of TDN. NDF is an estimate of the cellulose, hemicellulose, and lignin content in a sample. NDF is negatively correlated with forage intake, meaning that high-quality hay samples will have low NDF levels. CP is a measure of the total amount of protein in a sample of hay. RFV is a metric

Table 1. Alfalfa quality guidelines

Quality grade	ADF	NDF	RFV	CP	TDN
Supreme	<27	<34	>185	>22	>62
Premium	27–29	34–36	170–185	20–22	60–62
Good	29–32	36–40	150–170	18–20	58–60
Fair	32–35	40–44	130–150	16–18	56–58
Utility	>35	>44	<130	<16	<56

Notes: Sourced from USDA AMS. Guidelines for alfalfa hay for domestic livestock use. Hay should not include more than 10% grass.

measuring the joint digestibility and intake potential of hay (USDA AMS, n.d. b). The quality of hay improves as its relative feed value increases. RFV is the biggest determinant of the quality classification that hay receives (USDA NCRS, 2000).

The measurable differences in hay from one quality grade to the next have definitive implications on animal performance. Feeding alfalfa hay of relatively higher quality has been shown to result in increased milk production within dairy cattle and increased weight gains in feeder cattle (Donker and Marten, 1972; Lacefield, 1988). Livestock producers recognize this positive correlation between hay quality and animal performance and have come to expect increased production value when feeding higher-quality hay. Mayland et al. (1998) demonstrated increased production value when feeding a higher-quality hay relative to a lesser quality hay to lactating dairy cows equal to approximately $15/ton of forage.

This increased production value results in increased willingness to pay for hay of higher-quality grades (Dant et al., 2017; Hopper et al., 2004). Hedonic hay pricing models have demonstrated the large impact of quality grades on sales prices with increased marginal values for hay associated with relatively higher-quality grades (McCullock et al., 2014; Peake et al., 2019; Rudstrom, 2004). Though the impact of quality grades on price is established in the literature, little is known about how this impact may change through time, especially considering the relative strength (i.e., price level relative to historical levels) of the hay market at any given time. Can we assume the premiums by quality grade are constant during periods of elevated (depressed) hay market prices? The primary objective of this study is to determine if the magnitude of premiums and discounts received for differing quality grades of alfalfa hay are influenced by the level of the average market price for alfalfa hay relative to historical price levels. When the market is characterized by elevated prices (EP), does this affect the premiums received for hay of relatively high-quality grades in the same way it affects the discounts received for hay of relatively low-quality grades? Likewise, when the market is characterized by depressed prices (DP), are the effects on premiums and discounts the same? This study intends to provide answers to these questions.

Understanding the effect of average market price on the premiums and discounts received has direct implications for alfalfa hay producers and buyers. As demonstrated by Donker and Marten (1972), harvesting at different stages of maturity affects both quality and yield. An early harvest results in higher average quality but lower average yields in comparison to a later harvest. By understanding the effect that average market price has on premiums and discounts received for quality grades, an alfalfa hay producer can make more informed production and harvest timing decisions. Likely, these decisions are constrained by expected weather conditions as well as harvest timing considerations of future cuttings within a production year. Yet, our results would inform producers evaluating timing decisions on the margin to be better positioned to weigh the benefits of higher-quality hay compared with the cost of expected yield losses when considering harvest timing.

2. Data and methods

Though alfalfa hay is a common commodity, obtaining consistently reported regional sales and price data can be challenging. There are no futures markets for alfalfa hay and only limited price reporting. Additionally, it is common for alfalfa hay to be grown and fed to livestock within the same operation. When this occurs, no market transaction takes place for this hay, resulting in an incomplete price discovery process. The market price for this hay is not established, which further impacts the volume of hay pricing data available. The USDA Agricultural Marketing Service (AMS) publishes weekly direct hay reports for many of the forage-producing states/regions that include sale price information and hay quality grades (USDA AMS, 2024). Data for this study was compiled from these weekly direct hay reports across 15 states/regions from January 2000 to January 2024.[1]

The dataset has a structure that aligns with repeated cross-sectional data. While the dataset spans a significant timeframe (January 2000–January 2024) with weekly observations, each time point captures transactions reported from an unidentified set of individuals (USDA AMS, 2016). Many of these individuals may consistently report prices through time. However, within any given week, new individuals may report prices, or previous individuals may have nothing to report and would be excluded. As no individual identifying information is included in the reports, each observation must be treated as independent (USDA AMS, 2016). This focus on independent samples at each time period, rather than following the same units over time, characterizes repeated cross-sectional data. In repeated cross-sectional data, the focus is on capturing snapshots of the population at multiple points in time, allowing for the analysis of changes and trends within the population, despite the samples being independent across time periods.

While the hay transaction reports furnished by USDA AMS contain information on multiple varieties of hay, the observations in the dataset created for this analysis were constrained to only include alfalfa. Each observation in the dataset recorded transactional information including the sale price, sale report date, quality grade, bale type, and a variable indicating if the sale price included delivery to the buyer. Observations in the dataset were further constrained to only include transactions for which the sale price was reported on a dollar-per-ton basis. This constraint removed observations for which sales were reported on a dollar-per-bale basis. These per bale transactions could be retained by converting to a per ton basis using assumed bale weights. However, the assumptions around bale weights would add uncertainty and variability to these converted transactions. Additionally, the overall size and balance across bale types for this dataset were not critically impacted by the removal of the per bale transactions. Thus, for these reasons, as well as to maintain consistency across reported sales, we chose to remove the per bale transactions from the final dataset.

The summary statistics for the alfalfa hay sales in the USDA AMS direct hay reports used in this study are outlined in Table 2. The dataset consisted of 26,696 observations. Each transaction was designated to one of the five USDA quality grades: utility, fair, good, premium, or supreme. For this study, the utility and fair grades were combined into a single utility/fair category. Only 1.45% and 16.49% of total observations were of utility and fair grades, respectively. The limited reporting among these grades necessitated this change to help provide greater balance across the observed quality grades. Additionally, the mean real prices for all observations of utility and fair-quality hay were \$212.72/ton and \$225.30/ton, respectively. These relatively similar mean prices provided further justification for the combining of these two quality grades. The observations included in the dataset were constrained to the following bale types: large round, 4 × 4 square, 3 × 4 square,

[1]At the time of this analysis, there were 16 total state/regional hay reports published by the USDA AMS. We included all states/regions in this analysis except for Alabama, which was excluded as there were no alfalfa hay sales reported for the period of our dataset (January 2000–January 2024). Since completion of the analysis, three additional states have begun reporting including Arizona, Utah, and Tennessee and could be included in future analyses as their respective sample sizes grow to sufficient size.

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Table 2. Alfalfa hay summary statistics by quality grades from USDA AMS direct hay reports (January 2000–January 2024)

	Price received[a]				
Quality grade	Utility/fair	Good	Premium	Supreme	All qualities
Mean	$222.02	$248.72	$300.39	$314.89	$275.33
Standard deviation	60.92	63.24	69.92	68.35	75.04
Median	$209.21	$237.13	$296.99	$307.89	$266.89
Minimum	$59.81	$89.84	$76.99	$144.03	$59.81
Maximum	$458.67	$515.28	$592.62	$592.62	$592.62
Bale type	Utility/fair	Good	Premium	Supreme	% of total
Large round	1468	765	187	78	9.36%
4 × 4 square	1311	2715	3466	2634	37.93%
3 × 4 square	1819	1887	1588	736	22.59%
3 × 3 square	44	167	517	222	3.56%
2-tie small square	83	1555	3040	1782	24.20%
3-tie small square	65	131	416	20	2.37%
Total	4790	7220	9214	5472	26,696
Report location[b]	Utility/fair	Good	Premium	Supreme	% of total
California	219	289	400	172	4.05%
Colorado	49	120	172	43	1.44%
Idaho	208	61	53	30	1.32%
Iowa	0	31	34	11	0.28%
Kansas	2313	1162	519	554	17.04%
Missouri	122	122	122	122	1.83%
Montana	102	134	44	9	1.08%
Nebraska	77	429	91	39	2.38%
New Mexico	129	130	960	0	4.57%
Oklahoma	12	98	107	68	1.07%
Oregon	49	183	319	54	2.27%
South Dakota	104	84	89	90	1.37%
Texas	1120	4094	6014	4253	57.99%
Columbia Basin	206	76	79	13	1.40%
Wyoming	80	207	211	14	1.92%
Report locationb	Utility/fair	Good	Premium	Supreme	% of total
Delivered[c]	44.20%	49.75%	47.05%	59.48%	49.81%

[a]Prices are real prices ($/ton) with a 2023 reference year deflated using the CPI.
[b]As designated by the USDA AMS direct hay reports.
[c]Percent of observations that included delivery to the purchaser in the sale price.

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3 × 3 square, 2-tie small square, and 3-tie small square. Within the AMS reports, some transactions were listed as "large square" bales. These transactions were combined with the "4 × 4 square" transactions. Average prices for the bale sizes suggest the "large square bales" aligned more closely with the "4 × 4 square bales" rather than the "3 × 4 square bales." This consolidation enhances model parsimony without compromising the explanatory power or applicability of the results.

The dataset is well balanced across bale types and quality grades, while across states/regions, the data is limited by a notable imbalance. Specifically, 57.99% and 17.04% of all observations are from the Texas and Kansas direct hay reports, respectively. No other state or region included in the dataset accounted for more than 5% of total observations. While this constrains the generalizability of our findings geographically, overall, the variation in the dataset provides a strong foundation to begin to address the objectives of this study.[2]

With a goal to understand the effect of the market's strength on premiums and discounts received for various quality grades, it is necessary to characterize the price level (i.e., market strength) at a given point in time when a hay transaction is recorded. To do this, the monthly national average alfalfa hay price was retrieved from USDA NASS (2024b) for the same years as our hay transaction dataset (January 2000–January 2024). The consumer price index was used to convert from nominal to real prices with a reference year of 2023 (BLS, 2024).

2.1. Methodology

To quantify the condition of the alfalfa hay market at a given point in time, we rely on the real monthly national average alfalfa hay price series. Months within this series with prices in the bottom 25th percentile of all monthly average prices were labeled with a dummy variable, *DP*, equal to 1 if the average monthly price was in the bottom 25th percentile (depressed price) and equal to 0 otherwise. Similarly, months with average prices in the top 25th percentile (elevated prices) were designated with the dummy variable, *EP*. Months falling between the 25th and 75th percentiles were considered to reside in a "typical price (TP) period."

Real prices are necessary to use to identify the price periods (EP, DP, and TP) primarily when you consider the upward-trending nominal alfalfa hay prices in conjunction with upward-trending inflation throughout the period of our dataset (2003–2024). Considering these trends suggests that if nominal prices are used to determine the EP and DP periods, the likelihood of identify EP periods would increase with time, while the likelihood of identify DP periods would decrease with time. This implies that inflation must be controlled for to more accurately identify EP and DP periods. With upward-trending inflation, it is not possible to correctly identify the market price periods through time without analyzing real prices. Prices within this study were deflated using a general consumer price index published by the Bureau of Labor Statistics (BLS) (BLS, 2024) with 2023 used as the base or reference year.

After categorizing monthly observations within the USDA NASS national average price dataset into their respective price periods, all observations in the alfalfa direct hay report dataset were similarly categorized into their respective periods. This was accomplished by aligning each observation with the appropriate price period dummy variable based on the month and year in which the hay transaction took place. As an example, the average real alfalfa price as reported by USDA NASS in January 2000 was among the bottom 25th percentile of all months' average real prices. Consequently, all hay transactions from January 2000 were coded as belonging to a DP period. Designating the hay transactions as belonging to DP and EP periods based on the national average real price offers a consistent and interpretable framework for identifying significant deviations from typical market conditions. This method is not without limitations. Using the

[2]Exploratory models also revealed that the estimated coefficients of "4 × 4 square bales" and "large square bales" exhibited comparable magnitudes, indicating similar marginal values.

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national average price series to quantify market price strength assumes that national average prices adequately reflect localized market conditions despite potential regional variations in supply and demand. Local market conditions may vary from national trends due to factors such as regional weather and other production conditions. While regional variations exist, the national average serves as a reasonable proxy for underlying market strength, especially in the absence of localized data that comprehensively covers all relevant regions and time periods. The method is both practical and effective for identifying broad economic trends and dynamics that affect localized hay market prices.

An ordinary least squares (OLS) regression model was developed to evaluate the effect of the price periods (DP and EP) on the real price received for alfalfa as in

$$\begin{aligned} Real\_Hay\_Price_i = {} & \beta_1 + \beta_2 Year_i + \beta_3 Delivered_i + \beta_4 Utility/Fair_i + \beta_5 Premium_i + \beta_6 Supreme_i \\ & + \beta_7 Large\_Round_i + \beta_8 2\_Tie\_Small\_Square_i + \beta_9 3\_Tie\_Small\_Square_i \\ & + \beta_{10} 3x3\_Square_i + \beta_{11} 3x4\_Square_i + \beta_{12} EP_i + \beta_{13} DP_i \\ & + \beta_{14} EPXUtility/Fair_i + \beta_{15} EPXPremium_i + \beta_{16} EPXSupreme_i \\ & + \beta_{17} DPXUtility/Fair_i + \beta_{18} DPXPremium_i + \beta_{19} DPXSupreme_i + \varepsilon_i \end{aligned} \quad (1)$$

where $Real\_Hay\_Price_i$ is the real sales price of alfalfa hay (2023 dollars) for the ith observation received by the seller; $Year_i$ is a continuous time trend; $Delivered_i$ is a binomial variable indicating if delivery to the buyer was included in the real sales price; $Utility/Fair_i$, $Premium_i$, and $Supreme_i$ are binomial variables indicating the quality grade of an observation; $Large\_Round_i$, $2\_Tie\_Small\_Square_i$, $3\_Tie\_Small\_Square_i$, $3x3\_Square_i$, and $3x4\_Square_i$ are binomial variables indicating the bale type of an observation; EP_i and DP_i are binomial variables which indicate if an observation occurred in either a EP or DP period, respectively; and ε_i is the random error term. Table 3 provides definitions for all variables used in the analysis.

It was hypothesized that the parameter estimate for *Delivered* would have a positive sign. This can be deduced as it is a reasonable assumption that there is added value in the product being delivered, which would be reflected in the price received. All quality grades were included in the model with the exception of *Good*. The remaining three quality grades (*Utility/Fair, Premium*, and *Supreme*) would have parameter estimates that show the expected relationship between each grade relative to *Good* quality. Thus, it was hypothesized that *Utility/Fair* would have a negative sign for the parameter estimate while *Premium* and *Supreme* would have positive signs for their respective parameter estimates as suggested by previous literature (Hopper et al., 2004; McCullock et al., 2014; Peake et al., 2019). The bale type 4 × 4 Square was dropped from the model, resulting in the parameters for all other bale types being estimated relative to *4 × 4_Square*. Based on the work of McCullock et al. (2014) and Peake et al. (2019), it was hypothesized that *Large_Round* would have a negative sign for its parameter estimate and both *2_Tie_Small_Square* and *3_Tie_Small_Square* would have a positive sign for their respective parameter estimates. Peake et al. (2019) concluded that bale weight had a negative effect on price/ton. For this reason, it was hypothesized that the parameter estimates for *3 × 4_Square* and *3 × 3_Square* would have positive signs, indicating a positive impact on price/ton compared to the relatively heavier *4 × 4_Square* bales.

It was hypothesized that the variables representing DP periods and EP periods would have negative and positive parameter estimates, respectively. Intuitively, one would expect a negative marginal effect to be estimated for *DP*, suggesting the price of alfalfa hay transactions would be lower on average during DP periods, with the opposite intuition holding true for *EP*. Interaction terms for the respective price periods and quality grades were included within equation (1). Due to limited knowledge from prior research, no attempt was made at hypothesizing signs for the parameters of these interaction variables. Evaluating the signs, magnitudes, and statistical

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Table 3. Variable definitions

Variable	Variable type	Description
Real_Hay_Price	Continuous	Inflation adjusted price using Bureau of Labor Statistics' Consumer Price Index (2023 base year)
Year	Trend	Linear trend
Delivered	Binomial	1 if delivered, 0 if otherwise
Utility/Fair	Binomial	1 if grade is utility or fair, 0 if otherwise
Good	Binomial	1 if grade is good, 0 if otherwise
Premium	Binomial	1 if grade is premium, 0 if otherwise
Supreme	Binomial	1 if grade is supreme, 0 if otherwise
Large_Round	Binomial	1 if bale type is large round, 0 if otherwise
4 × 4_Square	Binomial	1 if bale type is 4 × 4 square, 0 if otherwise
3 × 4_Square	Binomial	1 if bale type is 3 × 4 square, 0 if otherwise
3 × 3_Square	Binomial	1 if bale type is 3 × 3 square, 0 if otherwise
2_Tie_Small_Square	Binomial	1 if bale type is 2-tie small square, 0 if otherwise
3_Tie_Small_Square	Binomial	1 if bale type is 3-tie small square, 0 if otherwise
DP	Binomial	1 if in depressed price (DP) period, 0 if otherwise
EP	Binomial	1 if in elevated price (EP) period, 0 if otherwise
DP × Utility/Fair	Binomial	1 if DP period and grade is utility/fair, 0 if otherwise
DP × Good	Binomial	1 if DP period and grade is good, 0 if otherwise
DP × Premium	Binomial	1 if DP period and grade is premium, 0 if otherwise
DP × Supreme	Binomial	1 if DP period and grade is supreme, 0 if otherwise
EP × Utility/Fair	Binomial	1 if EP period and grade is utility/fair, 0 if otherwise
EP × Good	Binomial	1 if EP period and grade is good, 0 if otherwise
EP × Premium	Binomial	1 if EP period and grade is premium, 0 if otherwise
EP × Supreme	Binomial	1 if EP period and grade is supreme, 0 if otherwise

Table 4. OLS results (Equation 1) for the effect of elevated and depressed price periods on alfalfa hay prices of varying quality grades

Variable	Parameter estimate	Standard error
Constant	178.836***	1.450
Year	1.971***	0.071
Delivered	37.830***	0.685
Utility/Fair	−19.043***	1.619
Premium	41.855***	1.269
Supreme	54.522***	1.434
Large_Round	−58.980***	1.370
2_Tie_Small_Square	61.014***	0.808
3_Tie_Small_Square	35.824***	2.177
3×3_Square	−25.334***	1.841
3×4_Square	−17.609***	1.090
DP	53.318***	1.336
EP	−29.035***	1.702
EP × Utility/Fair	−1.636	2.041
EP × Premium	0.790	1.732
EP × Supreme	−2.086	1.980
DP × Utility/Fair	−15.665***	3.404
DP × Premium	−10.107***	2.193
DP × Supreme	−5.209**	2.477

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.
N = 26,696; F-value = 1942; adjusted R-squared = 0.5669.

significance of these parameter estimates is central to the objectives of this study. Plausible arguments could be made for both negative and positive signs for these variables. For example, it could be hypothesized that the *DP X Supreme* parameter might be negative. If high supply drives the lower relative prices, and demand for supreme-quality hay is relatively less elastic than for good-quality graded hay, this would result in a decreased price for supreme-quality hay relative to good-quality hay in DP periods. Conversely, if the demand for supreme-quality hay in a DP period is more elastic than good-quality graded hay, then a positive parameter estimate would be expected. Additional supply and demand relationships, together with strategic production decisions in times of relatively low/high prices, may result in positive or negative estimated effects for these interaction terms. This study seeks to provide evidence for the direction and magnitude of movement in the premiums and discounts associated with quality grades during the EP and DP periods.

3. Results and implications

Equation (1) was estimated using ordinary least squares regression, and the results are summarized in Table 4. The results indicate that bale type, quality grade, *Year*, and *Delivered* all significantly influenced the price received. The adjusted R-squared of 0.5669 indicates that over half of the variation in the real price received for the observations in the model is explained by the

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included explanatory variables. The intent of this model was not to capture all variables that affect alfalfa hay prices. Rather, the model intends to understand the effect of the relative price level of the alfalfa hay market on prices received for individual transactions. Additional variables could have been included in the model to increase the goodness of fit.[3] However, if omitted variables are uncorrelated with quality grades and the DP and EP periods, their omission is expected not to affect the model findings with respect to the objectives. The parameter estimate for *Year* is 1.971, statistically significant at the 1% level. This indicates that the marginal effect of each additional year is an increase of $1.91/ton of alfalfa hay on average. This suggests that even after accounting for inflation, prices are trending upward year over year on average by $1.91/ton. Increased export demand over the years of this dataset (Putnam et al., 2016) in conjunction with decreased US production of approximately 31.6 million tons from 2000 to 2023 helps explain this positive trend (USDA NASS, 2024c). *Delivered* has a parameter estimate of 37.830 and is significant at the 1% level. On average, if the transaction included delivery to the buyer, this hay received a premium of $37.83/ton over hay that did not include delivery. This aligned with the hypothesized sign for this variable indicating increased marginal value for delivered hay.

The parameter estimates for each of the three quality grades included in the model relative to *Good* quality are statistically significant at the 1% level. *Utility/Fair* had a parameter estimate of −19.043, indicating that on average, holding all else equal, each ton of *Utility/Fair* hay received a price $19.04/ton lower than hay that was of the quality grade good. *Premium* and *Supreme* had parameter estimates of 41.86 and 54.52, respectively, indicating the average premiums in dollars per ton received for these respective quality grades relative to *Good.* These findings are consistent with both the hypothesized signs for these variables and the existing literature (Dant et al., 2017; Hopper et al., 2004; Mayland et al., 1998; McCullock et al., 2014; Peake et al., 2019).

The parameter estimates for each bale type included in the model are statistically significant at the 1% level. The 4x4 square bale type was omitted from the model and serves as the reference bale type when interpreting the parameter estimates of other bale types. Large round bales, 3×3 square bales, and 3×4 square bales are estimated as having average discounts relative to 4×4 square bales of $58.98, $25.33, and $17.61/ton, respectively, whereas 2-tie small square bales and 3-tie small square bales are expected to receive average premiums of $61.01 and $35.82/ton, respectively, relative to 4×4 square bales. These results align with the hypothesized sign for each variable with the exception of *3 × 4_Square* and *3 × 3_Square*. Contrary to the findings of Peake et al. (2019), even though these bales are lighter than a 4×4 square bale, they were discounted relative to the large 4×4 square bale. Though these bales are lighter, it is hypothesized that they receive a discounted price due to the limited popularity of these bale types within our dataset. As outlined in Table 2, there are over 10.5 and 1.6 times more observations for 4×4 square than 3×3 and 3×4 square bales, respectively. With 4×4 square bales being the most common bale size within the dataset, it could be hypothesized that other large bale sizes receive a discount because many operations may be set up to use 4×4 square bales. Therefore, it is possible that these bales receive less value due to the inefficiencies experienced by incorporating these smaller bale sizes.

Parameter estimates for both *DP* and *EP* were statistically significant at the 1% level. The results suggest that prices in DP periods and EP periods are expected to be $29.04/ton less and $53.32/ton more, respectively, on average than prices in TP periods. The price period variables were constructed as percentiles (top and bottom 25th percentile) of the national average real alfalfa prices reported by USDA NASS. The national average alfalfa prices are expected to correlate highly with the direct hay report prices in the corresponding time periods. Thus, the findings of direction and significance of the marginal effects of the price period variables are expected (nearly predetermined).

[3]State/region fixed effects were also considered. Due to the imbalance within the dataset across states/regions, we chose to omit this state/region variables from the model.

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The parameter estimates for the interaction between each of the three quality variables and price period variables are of much more importance to the accomplishment of this study's objectives. The coefficients for the quality interactions with the DP period were each estimated with a negative sign and are statistically significant at a maximum of the 5% level. The results suggest that utility/fair-quality hay in a DP period receives an additional price reduction on average of $15.67/ton relative to good-quality hay in the same price period. This discount would be applied together with the average discount of $19.04 for utility/fair hay regardless of the price period. Premium and supreme-quality hay in a DP period receive a price reduction of $10.11 and $5.21/ton, respectively, in comparison to good-quality hay in a DP period. This suggests that the price premiums for premium and supreme-quality hay shrink during DP periods, whereas the discount of utility/fair hay expands (larger disparity in favor of good-quality hay).

The parameter estimates for the interactions between the EP periods and the three included quality grades within the model vary in estimated sign, but none are found to be significant at the 5% level. Additionally, the magnitudes of these EP $\times$ quality grade interactions are much smaller compared to their DP period counterparts. The results imply that there is not enough evidence to suggest that periods of relatively high alfalfa prices have a consistent and significant effect on the marginal effects of quality grade premiums and discounts relative to good-quality hay.

Table 5 demonstrates the expected price of alfalfa hay by quality grade and price period while holding all else constant within equation (1). Additionally, the expected price premium/discount between each quality grade relative to "good" quality is displayed within Table 5. When comparing the premiums or discounts for each quality in the *DP* periods with the premiums or discounts in the TP periods, it becomes clear that the price premiums for premium and supreme-quality hay are reduced, whereas the price discount for utility/fair-quality hay widens. A comparison of the price premiums or discounts for each quality in the *EP* periods with the premiums or discounts during TP periods reveals no expected differences.

After empirical analysis through estimation of equation (1), a graphical analysis is completed for comparison. Figure 1 graphs the observed average price premiums or discounts by quality grade (relative to good) and price period within the dataset. A trendline was added for each quality grade spanning all three categories. Comparing the graphical results to those outlined in Table 5 adds robustness to the empirical findings. In the low-price era, average price premiums for premium and supreme-quality hay are reduced, while the average price discount for utility/fair-quality expands (more negative) in comparison to the TP periods. In EP periods, there is little variation in the price premiums or discounts for each quality grade when compared relative to TP periods. The linear trendlines in Figure 1 illustrate the idea that as transaction prices increase from depressed periods, the premiums received for premium and supreme-quality hay increase while the discounts received for utility/fair-quality hay are reduced.

Figure 2 similarly complements the empirical findings by graphing the price premiums and discounts relative to "good" quality through time. The same *DP* and *EP* variables used in the regression model are overlaid on this graph to highlight the price periods through time. If a given month had a value of 1 for *DP,* it was shaded red. Likewise, if a given month had a value of 1 for *EP*, it was shaded in green. While the trends may not be immediately clear, there are periods in Figure 2 where the findings from the regression model can be seen. For example, around 2009–2010, average prices were low, as indicated by the red shading, reflecting a DP price period. During this period, a trend emerged showing that utility/fair-quality hay was receiving a greater discount in comparison to good-quality hay. Two examples from the 2012–2014 and 2022–2023 periods illustrate similar findings to the regression model during these EP periods. Although there is variability in the premium received for supreme-quality hay compared to good quality, on average, the premiums received during these EP periods do not appear to differ significantly from those received in a normal era.

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Table 5. Expected alfalfa hay price[a] received by quality grade during periods of elevated, typical, and depressed average prices

	Depressed price period		Typical price period[b]		Elevated price period	
Quality grade	Est. price	Premium or discount[c]	Est. price	Premium or discount[c]	Est. price	Premium or discount[c]
Utility/Fair	$171.17	(−$34.71)	$215.87	(−$19.04)	$269.19	(−$19.04)
Good	$205.88	($0.00)	$234.91	($0.00)	$288.23	($0.00)
Premium	$237.63	($31.75)	$276.77	($41.86)	$330.09	($41.86)
Supreme	$255.19	($49.31)	$289.43	($54.52)	$342.76	($54.52)

[a]Prices were calculated by holding all variables from the estimated equation (1) at their means with the exception of price periods and quality grade. Coefficient estimates that were not found to be statistically significant were excluded.
[b]Typical price period is composed of all observations that do not fall into depressed or elevated price periods.
[c]Premium or discount is taken as the difference between the expected price of alfalfa hay in an assumed price period at a given quality grade and quality grade "good" within the same price period.

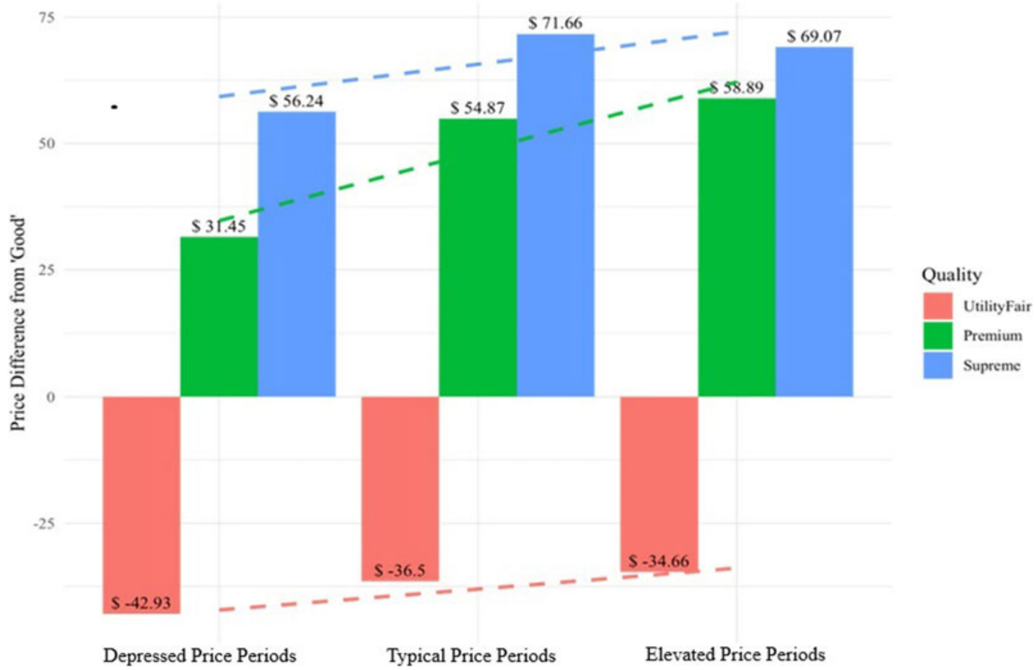

Figure 1. Average Price Differences by Quality Grade Relative to "Good" Quality by Price Period.

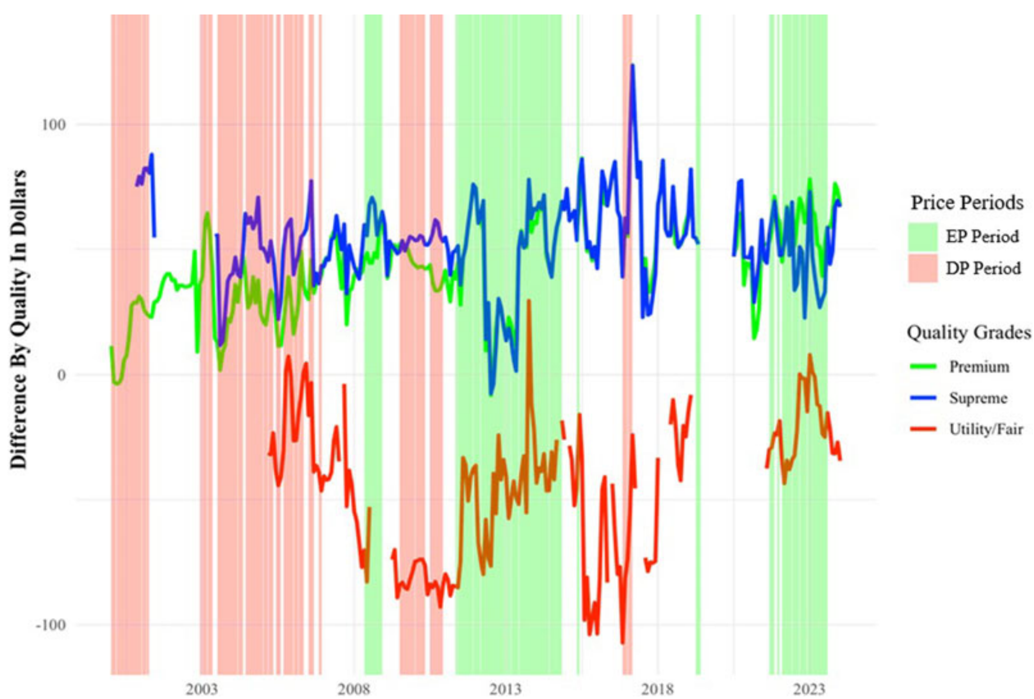

Figure 2. Average Price Premium or Discount through Time by Quality Grade Relative to "Good" Quality Notes: The premiums or discounts are calculated as is the difference from the average price for good quality hay for each of the average prices for the other hay quality grades. Elevated Price (EP) Period is all months that had an average price in the top 25% of all months. Depressed Price (DP) Period is all months that had an average price in the bottom 25% of all months.

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3.1. Implications

Understanding the effect of the relative strength of the alfalfa hay market on premiums and discounts received for varying qualities of hay could affect the decision-making for both producers and consumers. In DP periods, there may be occasions when pursuing increases in quality is not the optimal economic decision. As the premiums for premium and supreme-quality hay shrink relative to good, the economic advantage of producing higher-quality hay might be offset or even overcome by the increased yield of lower-quality hay. Individual producers must weigh the expected decrease in quantity with the decreased premiums for higher-quality grades during periods of low market prices when making production decisions. In periods of low average prices, if the added benefit of increased yield outweighs the now-reduced benefit of higher-quality hay, it may be in the best interest of the operation to, on the margin, forgo quality and pursue yield. Understanding the effect of average market prices on premiums and discounts for quality aids producers in making this decision.

Producers may often target higher-quality production, yet adverse production conditions or weather events may lead to undesirable reductions in quality. Our results suggest that, particularly in periods of low average prices, producers should make every effort to avoid utility/fair-quality production as prices for these low-quality grades are decreased disproportionately relative to good-quality hay.

Because this study found no statistically significant evidence suggesting that high average market prices affect individual quality grade premiums/discounts, producers should not become enamored with the comparatively higher average prices for premium and supreme-quality grade hay as compared to good during periods of relatively high prices. Our findings indicate that during periods of high prices, the value of good-quality hay increases by a similar magnitude as that of utility/fair, premium, and supreme-quality hay. The baseline price premiums/discounts associated with utility/fair, premium, and supreme-quality hay during TP periods remain unchanged during EP periods. There is no evidence found in this study suggesting that producers need to consider changes in production practices solely due to periods of above-average market prices.

Understanding the effects of low average prices could aid consumers in reducing their input costs. While alfalfa hay does not have an indefinite storage life, it is common for consuming firms to maintain stocks on hand. While all prices, regardless of quality grade, are expected to be reduced in periods of depressed average prices, the price for utility/fair is the most heavily discounted quality grade during DP periods. If a consuming firm can purchase and store utility/fair alfalfa hay for later use, they could potentially reduce their input costs by capitalizing on the heavily discounted expected prices for utility/fair-quality hay during these periods. On the contrary, the premiums received for supreme-quality hay are not as significantly impacted by low average prices. While consumers can still expect comparatively lower premiums required for these higher-quality grades relative to good quality during DP periods, the discounts expected for utility/fair hay would be of a comparatively larger magnitude. It is likely that operations that can feed utility/fair-quality hay already do so. If an operation typically purchases utility/fair-quality hay and it is anticipated that average prices will rise, there is no better time to purchase utility/fair-quality hay with the intent to create a supply stock than in a DP period.

Because the premiums and discounts received for varying qualities of alfalfa hay during EP periods are not significantly different than during TP periods, there is not a specific quality grade that is comparatively a better purchasing option during EP periods. During these periods, all quality grades are affected similarly, resulting in increased costs that are consistent across grades. There is not a particular quality grade that stands out as a comparatively better deal, and consumers should not expect to find one grade more advantageous than another solely based on being in an EP period.

When considering the practical implications of our results, it is perhaps not reasonable to expect that producers/consumers would be able to empirically identify the current price period in

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any given future week. To do so, it would first require referencing the current national average nominal alfalfa price. This price would then require adjustment for inflation using the CPI to accommodate comparison with the national average real price from 2003 to 2023. This limits the practical application of our results from an empirical perspective. Yet, this does not imply that the results are without practical implications. Extension educators armed with our results could identify the price period at any given time and could provide enhanced Extension education and recommendations to alfalfa producers during a production period. On an even more practical level, producers/consumers may benefit as they undoubtedly have a sense of the market in light of current nominal prices in conjunction with their own historical recollection of prices. Using this practical sense of the current strength of the market, producers and consumers could adjust decision-making at the margin to align with the implications of our findings.

4. Conclusions and discussion

This study revealed that various factors, such as quality and bale type, significantly influence the reported sale prices of alfalfa hay. Holding all other factors constant, utility/fair-quality alfalfa hay is expected to receive an average price of $19.04/ton less than good-quality hay. In contrast, premium and supreme-quality hay is expected to garner prices of $41.86/ton and $54.52/ton more than good-quality hay, respectively. Additionally, 2-tie small square and 3-tie small square bales garner premiums of $61.01/ton and $35.82/ton, respectively, compared to 4 × 4 square bales. Conversely, large round, 3 × 3 square, and 3 × 4 square bales are expected to incur discounts of $58.98, $25.33, and $17.61/ton, respectively, in comparison to 4 × 4 square bales.

This study successfully achieved its primary objective by uncovering how the level of the average market price for alfalfa hay influences the price premiums and discounts associated with quality grades. Particularly, in periods of low prices relative to average price levels, the impact on premiums for higher-quality hay and discounts for lower-quality hay varies. Transitioning from a normal average market price to a low average market price is expected to result in an additional decrease of $15.67/ton in the discount for utility/fair-quality hay compared to the price for good-quality hay. During this same transition, price premiums for premium and supreme-quality hay are expected to decline but to a lesser extent than the impact to the price discount for utility/fair hay. The price premium for premium quality hay is expected to decrease by $10.10/ton, while the premium for supreme-quality hay is expected to decrease by only $5.21/ton. When average market prices are high, however, the effect on the price premiums/discounts across quality grades is expected to be much more homogeneous. We estimate that all hay qualities experience an approximate increase in value of $53.32/ton with no significant differences across grades.

Although data from 15 states/regions was included, the results are limited by an imbalance in the observations across states/regions. The majority of observations originate from Texas and Kansas, accounting for 75.03% of all data points. Outcomes might vary if this imbalance could be corrected. Moreover, results may diverge for hay varieties beyond alfalfa. Subsequent investigations could concentrate on employing similar methodologies to explore diverse geographical markets and other types of hay.

One additional limitation of this study lies in the methodology used to identify EP and DP price periods. The chosen methodology does not capture whether EP or DP prices are driven by shocks to supply, demand, or a combination of both. Gaining insights into the factors influencing market price variation would enhance the study. For example, while it's reasonable to assume that abundant supply could lead to lower average prices, this study does not fully grasp how excess supply affects the premiums and discounts for various quality grades of alfalfa hay. Similarly, high demand might contribute to an upward trend in average alfalfa hay prices.

The method used for price period identification is also limited in its technical deployment by producers and consumers. This suggests that extension educators should aid in the more technical aspects of the dissemination of these results. However, producers and consumers are not constrained from benefiting from the result from an applied perspective given their own intuition concerning the current strength of the market. Future research should explore alternative methods for characterizing the market price level to better discern the impact of supply and demand dynamics on the premiums and discounts associated with different quality grades of alfalfa hay and enable producers/consumers to more fully participate in the technical aspects of price period identification.

Understanding the relationship between the average price level and the premiums/discounts for varying qualities of alfalfa hay is important for both producers and consumers. In times of low average prices, the decision to prioritize yield over quality may vary among operations, with some benefiting from pursuing higher yields considering reduced premiums for higher-quality hay. Conversely, operations specializing in lower-quality hay (utility/fair) may find it advantageous to improve quality during these times to offset the effect of expected increased discounts for lower-quality hay during these periods. However, during periods of elevated average prices, all quality grades are similarly affected, resulting in a consistently increased price for producers across the board. Therefore, there's no single quality grade that stands out as a better purchasing option for consumers during such times. Overall, understanding these dynamics can aid producers in optimizing production decisions and can assist consumers in managing input costs.

Data availability statement. The data that support the findings of this study are available from the corresponding author, [RF], upon reasonable request.

Author contributions. Conceptualization: R.F., C.W., R.L., and R.B.; data curation: R.F., C.W., and R.L.; formal analysis: R.F. and C.W.; investigation: R.F. and C.W.; methodology: R.F. and C.W.; project administration: R.F.; software: R.F. and C.W; supervision: R.F., R.L., and R.B.; validation: R.F., C.W., R.L., and R.B.; writing – original draft: R.F. and C.W.; writing – review and editing: R.F., C.W., R.L., and R.B.

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