# Losses and Quality Changes During Harvest and Storage of Preservative-treated Alfalfa Hay of Varying Moisture Content

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**ABSTRACT.** *Second- and third-cutting alfalfa hay was baled at moisture contents ranging from 11 to 38%. Treatments included control, buffered propionic acid applied at 0.2 or 0.3% of wet weight, and propionic acid applied at 0.5 or 1.0% of wet weight. Effects of moisture content at baling on harvest losses, storage losses, and pre- and post-storage quality were determined. Quality into storage [in vitro dry matter digestibility (IVDMD), acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP)] was not better for high moisture hay; quality after storage indicated benefits of baling lower moisture hay. Propionic acid reduced storage dry matter loss in hay with higher moisture levels. Neither chemical treatment had consistent significant effects on alfalfa quality. Of the in vitro digestible dry matter (IVDDM) placed into storage, approximately 94% was recovered after a 60-day storage period; recoveries of CP, ADF, and NDF were 99, 98, and 100%, respectively.* ***Keywords.*** *Alfalfa, Forage, Harvesting, Hay storage, Losses, Preservatives, Proprionates, Propionic acid, Quality.*

Annual U.S. hay production is worth nearly $10 billion (USDA, 1992). Economic losses during harvest, storage, and feeding of alfalfa hay amount to $25.50/Mg of dry matter (DM) available for animal use (Buckmaster et al., 1990). Reducing these losses is imperative for improving the efficiency and profitability of forage-based agriculture. Chemical preservatives allow for baling of hay at moisture levels up to 30% (Khalilian et al., 1990; Knapp et al., 1976; Nehrir et al., 1978). The motivation for using such preservatives is to reduce harvest losses without increasing storage losses and to retain (or even improve) quality.

Hay respiration is inhibited at moisture contents below 25% (Wood and Parker, 1971); therefore, the baling of hay at moisture levels of 25-30% rather than 18% should have no effect on respiration losses unless the hay is re-wetted. Due to reduced leaf shatter, a slight reduction in baling loss is expected as moisture content at baling is increased (Buckmaster et al., 1990). Also, because of the falling rate drying process, an increase in moisture content at baling by several percentage units can reduce field curing time by several hours. When this reduced curing time results in rain avoidance, losses are greatly reduced. While some effects of baling higher moisture alfalfa hay on harvest losses have been studied, the overall impact on hay quality has not been quantified.

Article was submitted for publication in July 1992; reviewed and approved for publication by the Power and Machinery Div. of ASAE in February 1993. Presented as ASAE Paper No. 90-1515.

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Rotz et al. (1992) thoroughly evaluated the potential for economical hay preservation using a simulation model which considers long-term weather patterns. With limited use (very selective application) of a hay preservative which eliminated mold but did not change DM loss or quality, the break-even treatment cost was near $7.20/Mg DM. The only way to achieve such a low cost is to reduce application rates; however, effectiveness with reduced application rates is not well known.

Use of propionic acid treatment has reduced storage loss in wetter (> 20% moisture) hay (Knapp et al., 1974; Davies and Warboys, 1978; Nehrir et al., 1978; Rotz et al., 1991), but storage loss was higher than that in dry hay (Rotz et al., 1991). However, storage losses of treated and untreated hay were similar after longer (six months) storage periods (Lacey et al., 1978; Rotz et al., 1991). The dry matter lost during storage is digestible material (Buckmaster et al., 1989); therefore, changes in DM loss should result in quality changes. Compared to untreated hay, propionic acid treated hay has had smaller decreases of IVDMD and *in vitro* cell wall digestibility (Knapp et al., 1976) and lower levels of ADF and acid detergent insoluble nitrogen (ADIN; Schaeffer and Clark, 1975). Other research has not shown consistent improvement of hay quality with propionic acid treatment (Davies and Warboys, 1978; Khalilian et al., 1990; Rotz et al., 1991). According to Rotz et al. (1991), acid-treated damp hay is generally lower in quality and less green in color than dry hay.

A major problem with propionic and similar acids is that they promote corrosion in balers and bale handling equipment. As a result, buffered acid products which reduce corrosion are being more widely used by those using hay preservatives. Buffered acid mixtures can be as effective as propionic acid if sufficient amounts of propionate are applied (Lacey and Lord, 1977). Since a major portion of the mixture is ammonia or another substance, greater application rates are often required. However, because the price per unit weight of such mixtures is generally higher than that of 100% propionic acid, application rates are often lowered to reduce the treatment cost. In limited testing, Rotz et al. (1991) evaluated one buffered acid mixture and found it to be ineffective when application rates were below 0.5%. The effects of baling and chemically treating higher moisture hay with lower application rates of buffered acids on nutritive quality and DM retention have not been well documented.

The objectives of this study were to:

- Determine the harvest and storage losses for alfalfa hay treated with propionic acid and a buffered propionic acid.
- Evaluate the nutritive quality before and after storage.
- Determine the effect of moisture content at baling on harvest and storage losses and nutrient recovery.

## METHODS

Five trials were conducted using second- and third-cutting alfalfa during the summers of 1989 (three trials) and 1990 (two trials). Chemical treatments of control, a 100% solution of propionic acid (P) and a 53% solution of esterified propionic acid (EP; Kemin Fresh Cut), were applied to alfalfa hay with two target moisture levels (15 and 25%). Chemical application rates for 15% moisture hay were 0.5% P or 0.2% EP; rates for 25% moisture hay were 1.0% P or 0.3% EP. Rates were selected based upon manufacturer recommendations for EP, a previous recommendation of three units propionic acid per unit of water in the hay (Benham and Redman, 1980), and at least 1% propionic acid needed on hay above 20% moisture.

Twenty bales (35×50×90 cm each) of each treatment/moisture level combination were stored for 60 days. The bales were stacked on edge inside a barn with each treatment stack being five bales wide and four bales high; treatment stacks were separated by at least 0.3 m of air space. All bales were weighed within 3 h of baling as well as at 30 and 60 days post harvest. Bales were returned to their original location after the 30-day sampling for the next 30-day storage period. The six interior bales were core sampled after each weighing. Two of the samples were combined forming three samples for nutritive analysis. The three samples were composited for crude protein (CP) and ADIN determination.

All samples were dried at 60° C for 72 h, then ground in a Wiley mill (1 mm screen). Total nitrogen was determined by the Kjeldahl method (AOAC, 1975) and expressed as CP; ADF and NDF were determined by methods described by Goering and Van Soest (1970). IVDMD was determined using a modified Tilley and Terry *in vitro* procedure as described by Martin and Barnes (1980).

During the last three trials, baling loss was collected on artificial alfalfa stubble as described in Buckmaster (1993). As the alfalfa was raked into the windrow, it was laid onto the artificial stubble. Immediately after baling, the material left on the artificial stubble was collected with a vacuum. Two replicate samples of baling loss were collected for each chemical treatment/moisture level combination. All samples were dried at 60° C for 72 h and analyzed for IVDMD and CP as outlined above.

Baler loss data were related to moisture content at baling using linear regression (Kleinbaum and Kupper, 1978; Statistix, 1989). The form of the regression model for baler DM loss and quality of baler loss material (IVDMD and CP) was:

$$Y = \beta_0 + \beta_1(m - 18) \tag{1}$$

where

$Y$ = characteristic being analyzed

$\beta$s = regression coefficients

$m$ = moisture content of the alfalfa at baling (%)

The expected value for alfalfa baled with a moisture content of 18% is given by $\beta_0$; $\beta_1$ indicates the effect of moisture content. The m–18 term was used so that $\beta_0$ could be interpreted as the expected value for hay baled with a "normal" moisture content.

Storage loss and quality data were also analyzed using linear regression with a transformed variable for moisture content at baling and indicator variables for chemical treatment, location, year, and cutting. The form of the regression model for storage DM loss, alfalfa quality (IVDMD or IVDDM, ADF, NDF, CP, and ADIN) as baled, quality through storage, and nutrient recovery (from storage) was:

$$\begin{aligned} Y = {} & \beta_0 + \beta_1(m - 18) + \beta_2{\cdot}X_{EP} + \beta_3{\cdot}X_P + \beta_4{\cdot}X_{EP,damp} \\ & + \beta_5{\cdot}X_{P,damp} + \beta_6{\cdot}X_{loc} + \beta_7{\cdot}X_{year} + \beta_8{\cdot}X_{cut} \\ & + \beta_9{\cdot}X_{year}{\cdot}X_{cut} + \beta_{10}{\cdot}X_P{\cdot}X_{loc} + \beta_{11}{\cdot}X_P{\cdot}X_{cut} \\ & + \beta_{12}{\cdot}X_P{\cdot}X_{year} + \beta_{13}{\cdot}X_{EP}{\cdot}X_{loc} + \beta_{14}{\cdot}X_{EP}{\cdot}X_{cut} \\ & + \beta_{15}{\cdot}X_{EP}{\cdot}X_{year} \end{aligned} \tag{2}$$

where

$X_{EP}$ = 1 for alfalfa treated with EP, 0 otherwise

$X_P$ = 1 for alfalfa treated with P, 0 otherwise

$X_{loc}$ = 1 for location 2, 0 for location 1

$X_{year}$ = 1 for 1990 data, 0 for 1989 data

$X_{cut}$ = 1 for 3rd cutting alfalfa, 0 for 2nd cutting

$X_{EP,damp}$ = 1 for alfalfa above 25% moisture treated with EP, 0 otherwise

$X_{P,damp}$ = 1 for alfalfa above 25% moisture treated with P, 0 otherwise

The first term ($\beta_0$) serves to define the loss or quality associated with the control alfalfa while the second "slope" coefficient ($\beta_1$) indicates the effect of moisture content at baling on DM loss or quality. This slope coefficient (which has not been determined elsewhere in the literature) should be useful in the future as researchers consider alternative harvest and preservation techniques. With the effects of cutting, year, and location removed, comparison of a chemical treatment (EP or P) to control was accomplished by testing the significance of the respective regression coefficients ($\beta_2$ or $\beta_3$). The additional effects of the chemical treatments on wetter alfalfa were determined by testing the significance of $\beta_4$ and $\beta_5$. The last 10 terms represent the effects of cutting, year, location, and potential interactions.

## Results and Discussion

### Moisture Content

Over the five storage trials, moisture content at baling varied from 11 to 38%. Previous evidence indicates that treated hay retains more moisture than non-treated hay (Rotz et al., 1991). This data exhibited the same trend with the untreated hay averaging 11.6% moisture after 60 days of storage. Average moisture levels of the EP- and P-treated hay were 12.2 and 13.2%, respectively.

### Baler Loss

The least squares average ($\beta_0$) of the amount of alfalfa collected on the artificial stubble (adjusted to 18% moisture at baling) was equivalent to 210 kg DM/ha. For a yield of 3.4 Mg DM/ha, representative of those in this study, this amounts to a 6.2% loss (table 1). This is reasonably consistent with the 4.3% suggested by Buckmaster et al. (1990) based on losses collected manually from field stubble. Although baler loss tended to decrease as moisture content at baling increased, the decrease was insignificant ($p > 0.10$).

The IVDMD of baler loss averaged 65.6% for 18% moisture hay at baling and decreased as moisture content at baling increased (table 1). The CP of baler loss averaged 23.3% for 18% moisture hay. Crude protein tended to decrease as moisture content at baling increased, but the effect was not significant ($p > 0.10$; table 1). The CP of lost material (23.3%) was higher than that of hay as baled (18.9%) as in Rotz and Abrams (1988) and numerous other reports.

### Quality of Baled Hay

For most evaluations, the effect of location, year, and cutting were significant ($p < 0.10$). Many times, these effects were of larger magnitude than the effects of P or EP. This may explain the inconsistencies of preservative effectiveness in the literature since many times these factors are not considered in the analysis. A few interaction terms were statistically significant ($p < 0.10$), yet not easily explainable. For example, treatment with P tended to increase fiber concentration in hay as baled, but only in 1990.

The IVDMD of the alfalfa as baled varied from 62.6 to 74.2%. The least squares mean for 18% moisture alfalfa was 65.8%. Moisture content at baling did not have a significant ($p > 0.10$) effect on IVDMD of the hay as baled, most likely because of the relatively small amount of baler loss and the fact that the IVDMD of the baler loss was similar to that of the hay baled. The IVDMD of baled hay was not affected ($p > 0.10$) by EP as expected, but P resulted in a 2.54 percentage unit increase of IVDMD in baled hay.

The ADF concentration of the alfalfa as baled varied from 30.3 to 41.0% of DM. The least squares mean for 18% moisture alfalfa was 36.3% (table 2). The ADF concentration of the hay as baled was not affected by moisture content at baling or either chemical treatment ($p > 0.10$). The NDF concentration of the baled alfalfa varied from 37.7 to 54.3% of DM. The least squares mean for 18% moisture alfalfa was 46.2% (table 2). The NDF concentration in baled hay was not affected by the moisture content at baling or either chemical treatment.

The CP concentration of the alfalfa as baled varied from 15.4 to 23.0% of DM. The least squares mean for 18% moisture alfalfa was 18.9% (table 2). Neither chemical treatment nor moisture content at baling affected ($p > 0.10$) CP concentration of the hay as baled. This is not in agreement with previous research (Buckmaster et al., 1990) which indicated that as moisture content at baling increased, the quality of baled hay increased. The lack of such a relationship in these data is likely due to the small magnitude of the expected differences which were not detectible within the levels of experimental error.

The ADIN concentration of the alfalfa as baled varied from 0.95 to 1.90% of total N (table 2). Neither moisture content at baling, nor chemical treatments had an effect ($p > 0.10$) on ADIN concentration of the hay as baled.

**Table 1. Effect of moisture content at baling on amount and quality of baler loss in alfalfa hay***

| Characteristic† | $\beta_0$ Least Squares Mean at 18% Moisture Content | $\beta_1$ Effect of Moisture Content at Baling |
|---|---|---|
| Baler DML (kg DM / ha) | 210 | NS |
| IVDMD of baler loss | 65.6 | –0.314‡ |
| CP of baler loss | 23.3 | NS |

* The statistical model is expressed as equation 1. Significance level is $p < 0.05$ for coefficients. NS refers to significance level of $p > 0.10$.

† DML = dry matter loss.
IVDMD = *in vitro* dry matter digestibility (%).
CP = crude protein (% of DM).

‡ Significance level is $0.05 < p < 0.10$.

**Table 2. Effects of moisture content at baling and chemical treatment, on alfalfa storage loss, quality of alfalfa at harvest, and quality throughout storage***

| Characteristic† | $\beta_0$ Least Squares Mean at 18% Moisture | $\beta_1$ Effect of Moisture Content at Baling | $\beta_2$ Effect of EP‡ | $\beta_3$ Effect of P | $\beta_4$ Effect of EP on Damp Hay | $\beta_5$ Effect of P on Damp Hay | R Correlation Coefficient |
|---|---|---|---|---|---|---|---|
| 30 d Storage DML | 3.20 | 0.681 | NS | 2.11 | NS | –4.71 | 0.314 |
| 60 d Storage DML | 4.29 | 0.697 | NS | 1.92 | NS | –5.35 | 0.364 |
| IVDMD as Baled | 65.8 | NS | NS | 2.54 | NS | NS | 0.813 |
| IVDMD after 30 d | 64.4 | –0.156 | NS | NS | NS | NS | 0.378 |
| IVDMD after 60 d | 64.0 | –0.196 | NS | NS | NS | NS | 0.463 |
| IVDDM Recovery§ | 0.936 | –0.00698 | NS | –0.046§ | NS | NS | 0.733 |
| ADF as Baled | 36.3 | NS | NS | NS | NS | NS | 0.656 |
| ADF after 30 d | 37.0 | 0.268 | NS | NS | NS | NS | 0.506 |
| ADF after 60 d | 37.1 | 0.248 | NS | NS | NS | NS | 0.582 |
| ADF Recovery | 0.982 | NS | NS | NS | NS | NS | 0.283 |
| NDF as Baled | 46.2 | NS | NS | NS | NS | NS | 0.865 |
| NDF after 30 d | 49.3 | 0.439 | NS | NS | NS | NS | 0.627 |
| NDF after 60 d | 48.1 | 0.411 | –1.87‖ | NS | NS | NS | 0.719 |
| NDF Recovery | 0.998 | 0.00341 | NS | NS | NS | NS | 0.688 |
| CP as Baled | 18.9 | NS | NS | NS | NS | NS | 0.982 |
| CP after 30 d | 19.0 | 0.0802 | NS | NS | NS | NS | 0.985 |
| CP after 60 d | 19.4 | NS | NS | NS | NS | NS | 0.986 |
| CP Recovery | 0.990 | –0.00449§ | NS | NS | NS | NS | 0.586 |
| ADIN as Baled | 1.35 | NS | NS | NS | NS | NS | 0.652 |
| ADIN after 30 d | 1.36 | 0.0390 | NS | NS | NS | NS | 0.736 |
| ADIN after 60 d | NS | NS | NS | NS | NS | NS | 0.680 |
| ADIN Recovery | NS | NS | NS | NS | NS | NS | 0.721 |

* The statistical model is expressed as equation 2. Significance level is $p < 0.05$ for coefficients. NS refers to significance level of $p > 0.10$.

† DML – dry matter loss (%).
IVDMD – *in vitro* dry matter digestibility (%).
IVDDM – *in vitro* digestible dry matter [% of dry matter (DM)].
ADF – acid detergent fiber (% of DM).
NDF – neutral detergent fiber (% of DM).
CP – crude protein (% of DM).
ADIN – acid detergent insoluble nitrogen (% of total N).

‡ EP – esterfied propionic acid.
P – propionic acid.

§ Recovery – quantity at end of storage period as a fraction of quantity entering storage (decimal).

‖ Significance level is $0.05 < p < 0.10$.

### Storage Loss

The least squares mean of 60-day storage loss for 18% moisture alfalfa was 4.29% (table 2). The $\beta_1$ of 0.697 indicated that increased moisture content at baling increased storage loss, with nearly a 0.7% increase in loss for each 1% moisture level increase at baling. Based on the data presented here, a 7% increase in moisture content (e.g., from 18 to 25%) would result in an added 4.9% [$0.697 \cdot (25-18)$] DM loss if no loss-reducing preservatives were added. This is similar to the data of Buckmaster et al. (1989), Rotz and Abrams (1988), and Rotz et al. (1991). The EP treatment had no significant effect on DM loss during storage. Treatment with P resulted in a slight increase in storage loss, but that increase was more than offset with a decrease in storage loss if the hay was above 25% moisture ($p < 0.05$; table 2).

Significant effects on loss and quality were similar for the 30-day and 60-day storage loss, but the data indicated that additional loss occurred (nominally 1% for 18% moisture hay) during the second month. For this reason, similar experiments of hay storage and preservation should be conducted for at least a 60-day period.

### Quality Changes During Storage

The IVDMD after 60 days of storage had a least squares mean of 64.0% for hay baled at 18% moisture (table 2). The post-storage IVDMD was negatively related to moisture content at baling; it decreased with a slope of 0.196 percentage units of IVDMD for each percentage unit increase in moisture content at baling. Increased moisture content at baling may increase the digestibility of the hay as baled; however, the increased moisture content resulted in more storage loss of digestible nutrients with a net loss in digestibility as moisture content at baling increased.

Recovery of IVDDM is the ratio of total IVDDM out of storage divided by total IVDDM into storage; the least squares average for 18% moisture hay was 93.6% (table 2). This indicates that 6.4% of the IVDDM into storage was lost during storage. Increasing moisture content at baling decreased IVDDM recovery, albeit only slightly. Application of P reduced IVDDM recovery. This is likely due to slightly higher DM loss. Treatment with EP had no effect on IVDMD or IVDDM recovery.

The ADF concentration after 60 days of storage had a least squares mean of 37.1% of DM for hay baled at 18% moisture (table 2). The post-storage ADF was positively affected by moisture content at baling and increased with a slope of 0.248 percentage units in ADF for each one percent increase in moisture content at baling. Recovery of ADF was 0.982, very near 1.0 as expected based on the model of Buckmaster et al. (1989). The chemical treatments did not affect ($p > 0.10$) ADF concentration nor ADF recovery.

The NDF concentration increased 1.9 percentage units during storage to a least squares mean of 48.1% for hay baled at 18% moisture (table 2). Since DM loss is a function of moisture content at baling and loss consists primarily of non-structural carbohydrates and protein (Rotz and Abrams, 1988), it would be expected that NDF and ADF concentrations out of storage also depend on moisture content at baling. These data exhibit this relationship with post-storage NDF increasing 0.41 percentage units for each 1% increase in moisture content at baling; post-storage ADF concentration also increased as moisture content at baling increased. Treatment of alfalfa with EP did decrease NDF concentration by 1.87 percentage units on average ($p = 0.09$), constituting the only post-storage effect of EP on hay quality. Treatment of the hay with P had no effect ($p > 0.10$) on NDF concentration. The NDF recovery for these experiments averaged 0.998, indicating that all DM loss was indeed non-NDF material.

Crude protein concentration out of storage (30 or 60 days) was not affected by either chemical treatment ($p > 0.10$, table 2). Increased moisture content at baling increased the 30-day CP concentration, but the effect was not significant after 60 days of storage. Total CP recovery (amount out of storage as a fraction of that entering storage) averaged 99% showing a 1% loss of CP during storage; these data showed better recovery than previous reports of 98 and 93.8% (Buckmaster et al., 1989; Rotz and Abrams, 1988). Neither chemical treatment affected CP recovery; however, baling of wetter hay decreased CP recovery slightly across all three treatments.

Variations in the ADIN concentration after storage and ADIN recovery were best explained with the interaction terms of equation 2. The concentration of ADIN post-storage, when adjusted for moisture content at baling and experimental effects, averaged 0.44% of total N and was not significantly ($p > 0.10$) affected by moisture content at baling nor chemical treatment (table 2). This low amount of ADIN reflects little heating. Temperature histories of the hay stacks (data not shown) indicated very few temperatures above the 35° C considered necessary for heat binding of protein. This may indicate that 20-bale stacks are insufficient for monitoring heating patterns when each stack has some air space surrounding it; however, smaller stacks have been used previously (Buckmaster et al., 1989; Rotz and Abrams, 1988; Rotz et al., 1991).

## Conclusions

Loss of alfalfa hay during harvest (at the baler) was 210 kg DM/ha on average for 18% moisture hay. IVDMD of the lost material was 65.6% and decreased 0.3% for each 1% increase in moisture content at baling. CP content of the lost material was 23.3%. After removal of main effects and interactions, the quality of hay as baled did not significantly increase as moisture content at baling decreased.

Dry matter loss during storage averaged 4.3% for alfalfa hay baled with 18% moisture and increased 0.7% for each percentage unit increase in moisture content at baling. Application of propionic acid on damp hay reduced DM loss slightly over 60 days of storage, but the buffered propionic acid treatment had no effect.

Concentrations of ADF, NDF, and CP increased during storage. IVDMD decreased due to the loss of digestible material. Changes during storage depended on moisture content at baling. The negative effects of storing wetter hay more than offset benefits of harvesting wetter hay. Retention ratios for ADF and NDF were near 1.0; retention ratios of IVDMD and CP were less than 1.0 and decreased with increased moisture content at baling. Neither propionic acid nor the buffered propionic acid had significant effects on nutrient concentrations before or after storage.

**ACKNOWLEDGMENT.** The financial support of Kemin Industries is appreciated. The technical assistance of G. Bush and C. Garman is gratefully appreciated.

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