# HAY PRESERVATION AND STORAGE LOSSES

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## ABSTRACT

The effects of several months storage of hay was studied to quantify changes in forage quality parameters. The acid detergent fiber (ADF) increased from 2.7 to 5.3% from initial to final points across all hays. The change in neutral detergent fiber (aNDF) was inconsistent for the 4 hays. The RFV index did not change in the alfalfa/grass mix hay, but declined by 14, 21, and 11 units in the other 3 alfalfa hays. The NDF digestibility in 48 hours (NDFD48, as % of NDF) declined an average of 2.9% across the 4 hays. The net energy for lactation (NE/Lact), digestible dry matter, relative feed value (RFV), and relative forage quality (RFQ) declined about the same magnitude across the 4 hays. Lignin, an indigestible fiber fraction, increased an average of 4.3% across the 4 hays. This paper documents the changes of hay quality in storage.

**Keywords: Alfalfa, *Medicago sativa*, hay storage, forage quality loss**

## INTRODUCTION

Hay loses weight (mass) and degrades in quality with the passage of time. The magnitude of storage losses is not well recognized by hay producers due to the difficulty of measurement. Harvested hay must be stored properly to minimize further degradation. Even in barn storage, shrinkage during several months is typically from 5 to 10% weight loss from fresh-baled hay, about 5% in dry matter loss and the remainder in moisture. Moisture content will reach an equilibrium level in relation to relative humidity. Hay moisture will stabilize at about 10% in arid climates, and about 15% in humid climates. The external surfaces of bales on sides of stacks can reach 19% moisture during winter. Several factors affect the storage and preservation of high-quality hay: forage species, maturity, harvest management, and storage management. Weathering effects: sunlight, heat, and precipitation, can be controlled with storage facilities, preservation materials, and proper storage management.

A study was conducted in 2013-2014 to quantify changes in forage quality parameters over a several month period. This paper provides information about the magnitude and causes of hay losses in storage and how management can minimize the losses.

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## METHODS

Two first-cutting and two second-cutting hay stacks were sampled by coring 10 bales on each side of stack at chest height. Stack A was first cutting alfalfa/orchard grass 50%/50% mixture in 3ft x 4ft x 8ft bales with a tarp on top. Stack B was first cutting alfalfa hay in 4ft x 4ft x 8ft bales. Stack C was second-cutting alfalfa hay in 4ft x 4ft x 8ft bales with a tarp on top. Stack D was second-cutting alfalfa hay 4ft x 4ft x 8ft bales, with elevated pad and tarped. Coring was done with a Star Quality Probe (0.5in diameter) to a depth of 14 inches in the butt end of bales: initial (soon after baling and stacking), mid-storage, and final. A composite cored sample, 20 from each stack, was mixed, sealed in plastic bags, and submitted for grinding. Subsequent cores were extracted from the same bales about 6 inches from the previous core. Samples from each sampling site and date were dried for at least 1 hour at 150°F (65°C) and ground through a 1-mm screen in a Udy Cyclone mill before quality analysis by near infrared reflectance spectroscopy by AgSource Laboratories (now Northwest Labs, LLC), Jerome, ID. Prediction equations for crude protein (CP), neutral detergent fiber (NDF), and neutral detergent fiber digestibility (NDFD) were calibrated by wet chemistry. Prediction equations for other measurements were provide by AgSource Laboratories

Caution! Since this was a case study the analysis is based on limited numbers of samples, analysis of variance statistical tests are not appropriate. The reader is cautioned to not assume the results are statistically significant. Stack B had 4 points on a time series, so the data were satisfactory for linear regression analysis. This is preliminary data and we continued the study in 2014 and 2015.

The sampling and laboratory error, assumed to be 5%, is used to estimate errors for several of the primary forage quality parameters in Table 1. The standard laboratory error for near infra-red reflectance spectroscopy (NIRS) analysis determined by Marten et al. (1989) is also given in Table 1. If the change in parameter values from this study is greater than the potential error for sampling and laboratory analysis, or the SLE listed in Table 1, there is some assurance the change is significant.

**Table 1**. Potential sampling and laboratory error in forage quality analysis. The standard laboratory error (SLE) for NIRS was determined by Marten et al. (1989).

| **Forage quality parameter** | **Concentration, %** | **@ 5% error** | **SLE** |
|---|---|---|---|
| Crude protein (CP) | 20 | 1 | 0.6 |
| Acid detergent Fiber (ADF) | 30 | 1.5 | 1.2 |
| Neutral detergent fiber (NDF) | 40 | 2 | 1.5 |
| Relative Forage Value (RFV) | 160 | 8 | |

## RESULTS AND DISCUSSION

Initial stack moisture concentrations were all below 8%, probably because of very dry baling conditions and limited precipitation during most of the storage period. Crude protein was lower in stack A (Table 2) than other stacks because the hay was 50% grass. Crude protein in stack A increased 2.1units from initial to final storage, but the 3 other stacks did not change for crude protein (Tables 3, 4, and 5).

**Table 2.** Forage quality parameters at beginning, mid, and ending points of storage. This stack was first cutting 3ft x 4 ft x 8 ft bales of alfalfa/grass (50%/50%) mixture baled on 30 June 2013 and stacked (tarp) on 1 July 2013. Concentrations are expressed as a percent of dry matter unless otherwise indicated.

| **Stack A 1st Cutting Alfalfa/Grass Mix** | **Initial** | **Mid** | **Final** | **Absolute Change** |
|---|---|---|---|---|
| **Assays by NIR** | **7/1 /2013** | **7/9 /2013** | **12/14 /2014** | **In 166 d** |
| Moisture as received, % | 7.8 | 7.5 | 6.5 | -1.30 |
| Dry matter as received, % | 92.2 | 92.5 | 93.5 | 1.30 |
| | | | | |
| Crude protein, % | 14.6 | 15.0 | 16.7 | 2.10 |
| Heat Dame. Protein, % | 0.6 | 0.6 | 0.7 | 0.10 |
| Acid Det. Fiber (ADF), % | 35.2 | 34.5 | 37.9 | 2.70 |
| aNDF, % | 46.3 | 45.9 | 44.7 | -1.60 |
| Ash, % | 9.20 | 9.20 | 8.50 | -0.70 |
| | | | | |
| Fat, % | 1.30 | 1.20 | 1.00 | -0.30 |
| Lignin, % | 5.7 | 7.1 | 8.1 | 2.40 |
| 48HR dNDF | 20.2 | 20.9 | 18.5 | 1.8 |
| NDFD48, % of NDF | 43.7 | 45.6 | 41.3 | -2.40 |
| | | | | |
| **Calculations** | | | | |
| Adj. Crude Protein, % | 14.6 | 15.0 | 16.7 | 2.10 |
| NE/LACT, MCAL/LB | 0.61 | 0.62 | 0.58 | -0.03 |
| Dig. Dry Matter, % | 61.5 | 62.0 | 59.4 | -2.10 |
| Relative Feed Value | 124 | 126 | 124 | 0.10 |
| Rel. Forage Quality | 120 | 126 | 123 | 2.80 |
| | | | | |
| Crude Fiber, % | 27.8 | 27.3 | 29.9 | 2.10 |
| TDN EST., % | 54.9 | 55.4 | 55.7 | 0.80 |
| Lignin as % NDF | 12.3 | 15.5 | 18.1 | 5.80 |

The acid detergent fiber concentration (ADF) increased from 2.7 to 5.3% from initial to final points across all hays. The change in neutral detergent fiber (aNDF) was inconsistent for the 4 hays. The RFV index did not change in the alfalfa/grass mix hay, but declined by 14, 21, and 11 units in the other 3 alfalfa hays. The NDF digestibility in 48 hours (NDFD48, as % of NDF) declined an average of 2.9% across the 4 hays. The net energy for lactation (NE/Lact), digestible dry matter, relative feed value (RFV), and relative forage quality (RFQ) declined about the same magnitude across the 4 hays. Lignin, an indigestible fiber fraction, increased an average of 4.3% across the 4 hays.

**Table 3.** Forage quality parameters at beginning, mid, and ending points of storage. Stack B was first cutting 4ft x 4 ft x 8 ft bales of alfalfa baled and stacked (no-tarp) on 14 June 2013. Concentrations are expressed as a percent of dry matter unless otherwise indicated.

| **Stack B 1st Cutting Alfalfa** | **Initial** | **Mid1** | **Mid2** | **Final** | **Absolute Change** |
|---|---|---|---|---|---|
| **Assays by NIR** | **6/14 /2013** | **7/24 /2013** | **11/7 /2013** | **1/28 /2014** | **in 188 d** |
| Moisture as received, % | 7.2 | 7.0 | 8.3 | 7.4 | 0.2 |
| Dry matter as received, % | 92.8 | 93.0 | 91.7 | 92.6 | -0.2 |
| | | | | | |
| Crude protein, % | 17.2 | 17.9 | 17.7 | 18.1 | 0.9 |
| Heat Damaged Protein, % | 0.5 | 0.5 | 0.4 | 0.6 | 0.1 |
| Acid Det. Fiber (ADF), % | 32.1 | 31.3 | 34.7 | 36.2 | 4.1 |
| aNDF, % | 39.7 | 38.6 | 39.9 | 39.8 | 0.1 |
| Ash, % | 10.2 | 10.3 | 12.1 | 9.50 | -0.7 |
| | | | | | |
| Fat, % | 1.80 | 1.80 | 1.3 | 1.70 | -0.1 |
| Lignin, % | 3.2 | 3.8 | 6.8 | 5.1 | 1.9 |
| 48HR dNDF | 17.2 | 16.9 | 16.2 | 15.2 | -2.0 |
| NDFD48, % of NDF | 43.2 | 43.9 | 40.5 | 38.1 | -5.2 |
| | | | | | |
| **Calculations** | | | | | |
| Adj. Crude Protein, % | 17.2 | 17.9 | 17.7 | 18.1 | 0.2 |
| NE/LACT, MCAL/LB | 0.65 | 0.66 | 0.6 | 0.60 | -0.1 |
| Dig. Dry Matter, % | 63.9 | 64.5 | 61.9 | 60.7 | -3.8 |
| Relative Feed Value | 150 | 156 | 144 | 142 | -13.6 |
| Rel. Forage Quality | 144 | 151 | 133 | 134 | -17.0 |
| | | | | | |
| Crude Fiber, % | 25.4 | 24.7 | 27.4 | 28.6 | 3.9 |
| TDN EST., % | 57.7 | 58.5 | 57.3 | 57.2 | -1.3 |
| Lignin as % NDF | 8.06 | 9.84 | 17.0 | 12.8 | 3.0 |

**Table 4.** Forage quality parameters at beginning, mid, and ending points of storage. Stack C was second cutting 4ft x 4 ft x 8 ft bales of alfalfa baled on 27 July 2013 and stacked (tarp) on 29 July 2013. Concentrations are expressed as a percent of dry matter unless otherwise indicated.

| **Stack C 2nd Cutting Alfalfa** | **Initial** | **Final1** | **Final2** | **Final (avg)** | **Absolute Change** |
|---|---|---|---|---|---|
| **Assays by NIR** | **7/29 /2013** | **1/23 /2014** | **1/23 /2014** | **1/23 /2014** | **in 147 d** |
| Moisture as received, % | 6.6 | 7.1 | 7.0 | 7.1 | 0.5 |
| Dry matter as received, % | 93.4 | 92.9 | 93.0 | 93.0 | -0.5 |
| | | | | | |
| Crude protein, % | 20.8 | 20.9 | 20.7 | 20.8 | 0.0 |
| Heat Damaged Protein, % | 0.6 | 0.7 | 0.8 | 0.8 | 0.2 |
| Acid Det. Fiber (ADF), % | 30.2 | 35.0 | 35.9 | 35.5 | 5.3 |
| aNDF, % | 36.8 | 38.3 | 40.7 | 39.5 | 2.7 |
| Ash, % | 11.0 | 9.3 | 8.7 | 9.0 | -2.0 |
| | | | | | |
| Fat, % | 1.70 | 1.50 | 1.10 | 1.3 | -0.4 |
| Lignin, % | 3.0 | 5.5 | 4.4 | 5.0 | 2.0 |
| 48HR dNDF | 14.5 | 13.9 | 17.0 | 15.4 | 0.9 |
| NDFD48, % of NDF | 39.4 | 36.3 | 41.7 | 39.1 | -0.4 |
| | | | | | |
| **Calculations** | | | | | |
| Adj. Crude Protein, % | 20.8 | 20.9 | 20.7 | 20.8 | 0.0 |
| NE/LACT, MCAL/LB | 0.67 | 0.62 | 0.61 | 0.6 | -0.1 |
| Dig. Dry Matter, % | 65.4 | 61.6 | 60.9 | 61.3 | -4.2 |
| Relative Feed Value | 165 | 150 | 139 | 145 | -20.8 |
| Rel. Forage Quality | 149 | 138 | 140 | 139 | -9.6 |
| | | | | | |
| Crude Fiber, % | 23.9 | 27.7 | 28.4 | 28.1 | 4.2 |
| TDN EST., % | 60.9 | 59.6 | 59.2 | 59.4 | -1.5 |
| Lignin as % NDF | 8.15 | 14.4 | 10.8 | 12.6 | 4.5 |

Final 1 and 2 samples from stack C (Table 4) are duplicate NIR analyses of the same composite core sample. Note that there are some differences in parameter values even in a 1-gram ground sample. This demonstrates the normal analytical variation, which is usually smaller than sampling variation.

**Table 5.** Forage quality parameters at beginning, mid, and ending points of storage. Stack D was second cutting 4ft x 4 ft x 8 ft bales of alfalfa baled and stacked on 24 July 2013 and tarped. Concentrations are expressed as a percent of dry matter unless otherwise indicated.

| **Stack D 2nd Cutting Alfalfa** | **Initial1** | **Initial2** | **Initial (avg)** | **Final** | **Absolute Change** |
|---|---|---|---|---|---|
| **Assays by NIR** | **7/24 /2013** | **7/24 /2013** | **7/24 /2013** | **1/28 /2014** | **in 189 d** |
| Moisture as received, % | 5.6 | 6.0 | 5.8 | 5.9 | 0.1 |
| Dry matter as received, % | 94.4 | 94.0 | 94.2 | 94.1 | -0.1 |
| | | | | | |
| Crude protein, % | 18.8 | 17.6 | 18.2 | 19.8 | 1.6 |
| Heat Damaged Protein, % | 0.6 | 0.5 | 0.6 | 0.6 | 0.0 |
| Acid Det. Fiber (ADF), % | 34.0 | 31.7 | 32.9 | 37.1 | 4.3 |
| aNDF, % | 41.1 | 39.1 | 40.1 | 41.0 | 0.9 |
| Ash, % | 10.8 | 10.2 | 10.5 | 9.60 | -0.9 |
| | | | | | |
| Fat, % | 1.60 | 1.90 | 1.8 | 1.50 | -0.3 |
| Lignin, % | 4.6 | 3.3 | 4.0 | 5.6 | 1.7 |
| 48HR dNDF | 17.0 | 16.1 | 16.6 | 15.4 | -1.2 |
| NDFD48, % of NDF | 41.5 | 41.1 | 41.3 | 37.5 | -3.8 |
| | | | | | |
| **Calculations** | | | | | |
| Adj. Crude Protein, % | 18.8 | 17.6 | 18.2 | 19.8 | 1.6 |
| NE/LACT, MCAL/LB | 0.63 | 0.65 | 0.6 | 0.59 | -0.1 |
| Dig. Dry Matter, % | 62.4 | 64.2 | 63.3 | 60.0 | -3.3 |
| Relative Feed Value | 141 | 153 | 147 | 136 | -11.0 |
| Rel. Forage Quality | 132 | 142 | 137 | 127 | -10.3 |
| | | | | | |
| Crude Fiber, % | 26.9 | 25.0 | 26.0 | 29.3 | 3.4 |
| TDN EST., % | 58.4 | 58.1 | 58.3 | 58.2 | 0.0 |
| Lignin as % NDF | 11.2 | 8.44 | 9.8 | 13.7 | 3.9 |

## Rate of Change

Stack B showed some consistent trends in assayed forage quality parameter changes (Figure 1). The crude protein did not change significantly. A small amount of crude protein was likely degraded, however, since the soluble carbohydrates (sugars and starch) are used by microbial respiration, ADF and lignin increase in concentration. Although the absolute amount of protein may decline a little, the loss of total dry matter results in the concentration of crude protein slightly increasing. Although NDF did not change, ADF increased 0.0243% each day of storage ($r^2$=0.89). In other words, the number of days of storage explained 89% of the variation in ADF concentration. Lignin increased 0.035% each day of storage ($r^2$=0.63). Although laboratory measurement and prediction by NIR of lignin is not precise, even small changes in lignin have a large impact on digestibility.

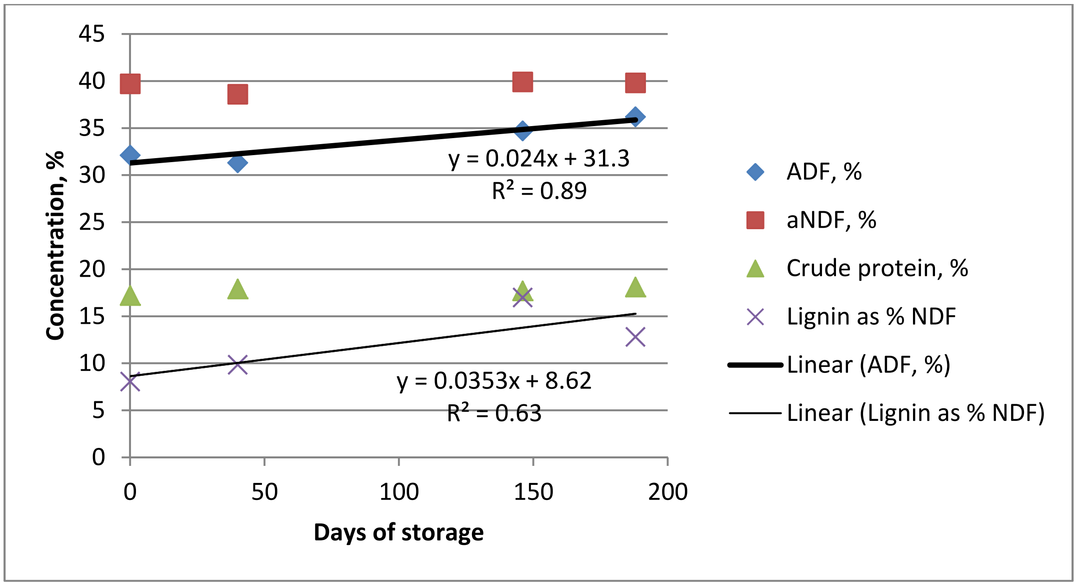


**Figure 1.** Rates of change of assayed forage quality parameters of stack B.

Stack B also showed consistent trends in calculated or predicted forage quality parameters (Figure 2). Relative Feed Value (RFV) declined -0.057 index points for each day of storage ($r^2$=0.69). Relative Forage Quality (RFQ) declined -0.080 index points for each day of storage ($r^2$=0.72). The estimated Total Digestible Nutrients (TDN) did not change much.

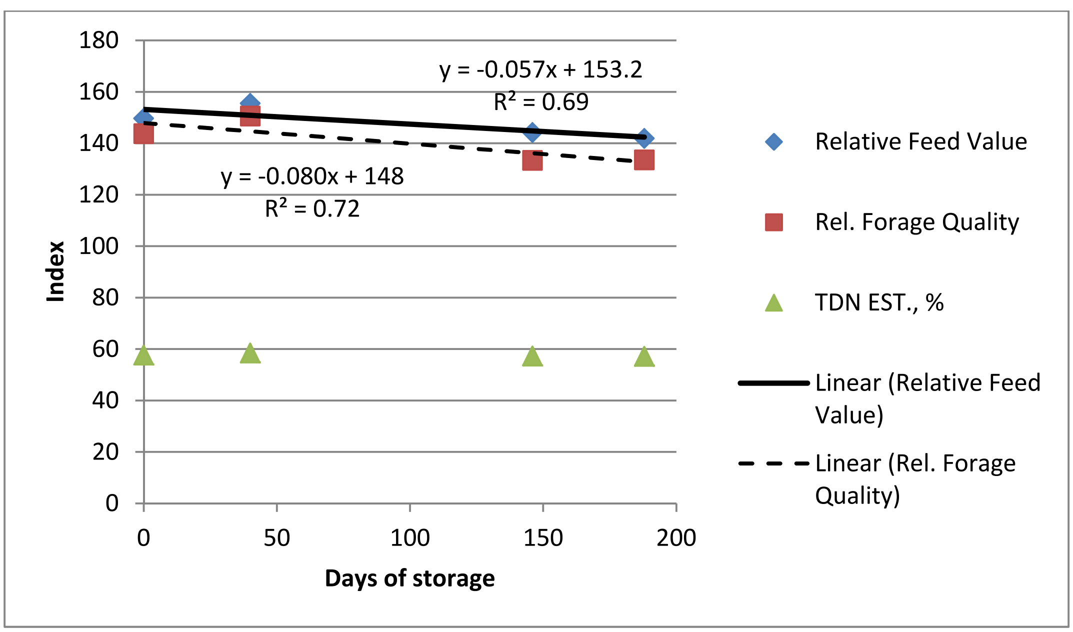


**Figure 2.** Rates of change of calculated forage quality parameters of stack B.

## SYNTHESIS OF THE LITERATURE

### Moisture Effects on Tonnage and Quality

Hay with less than 15% moisture is relatively stable and little respiration occurs. Alfalfa hay baled at 16% moisture can be expected to lose 3.5% of its dry matter (mass) in four months. Anderson et al. (1981) showed that storage dry matter losses average three percent of harvested dry matter weight for indoor storage and 14 percent for outside storage. Rotz and Abrams (1988) reported changes in untreated alfalfa hay during 6-months storage were 5% dry matter loss in hay baled from 11 to 20% moisture. Losses are greater--up to 10% loss of dry matter--in hay baled at higher moisture levels. Alfalfa hay baled at 16% moisture and stored as a stack outside on the ground for 6 months in Pennsylvania lost 11.3% of the initial dry matter (Nehrir et al. 1978). Hay baled at 13% moisture with high leaf shatter will not decrease in quality as much as hay baled at 20% moisture with little leaf shatter.

Higher moisture provides a significant opportunity for mold growth and other micro biotic activity. In hay containing more moisture, microbial respiration causes the hay to heat during the first 3 to 5 weeks of storage. The amount of heating and the associated loss increase with moisture content. Dry matter losses during the first month of storage vary from 1% in hay of 15% moisture to 8% in 30% moisture hay (Nelson, 1966, 1968; Rotz et al., 1991). Although a major portion of the loss may occur in the first month, a small loss of about 0.5% DM per month continues throughout storage even in dry hay (Rotz et al., 1991).

Small rectangular hay bales are likely to develop visible mold when baled with moisture levels above 20%. Large round or rectangular bales are likely to develop mold at when baled at 18% moisture. Large rectangular bales (1/2 to 1 ton) should have moisture levels less than 16% if no preservatives are used to minimize dry matter loss.

### Weathering Effects

Dry matter losses can be as low as 3% for hay stored in a barn or as high as 15% for similar bales stored outside on soil or sod surface over winter. Quality losses can be as high as 14% for bales stored outside. Solid plastic-wrapped bales that are ensiled may lose from 10 to 25% of dry matter and quality.

Moisture content of bales stored outside on soil without covers increases sharply during storage. The outer 2 to 3 inches of the bale may increase in moisture by as much as 120%. A 1-inch rain adds about 20 gallons of water to a 4-foot x 8-foot bale surface. Weathering begins slowly, but once a wet layer forms, a bale does not shed water well and moisture levels inside the bale are likely to continue to increase. The wet, moldy area on the top of the bale deepens, and less drying occurs between rains. The best strategy is to prevent weathering initially and to limit exposure of hay to weathering as much as possible.

Weathering can also occur from the ground. Dry hay touching damp soil or concrete draws moisture into the bale. If hay and soil are in contact up to 50% of total dry matter loss in storage may be in the bottom bale(s). Russell and Huhnke (1997) reported different storage conditions and compared them to barn storage. Only 87% of digestible dry matter is conserved when stacked outside, on the ground, and uncovered compared with barn storage. Covering with plastic and stacked on a raised surface conserved 97% of dry matter compared to barn storage.

### Climatic Factors and Outside Storage

High humidity slows drying of stacked wet hay. Warm, humid, and overcast conditions favor microbial growth in hay. Cold, arid, and sunny conditions are unfavorable to microbial growth in hay. Well-ventilated conditions are also conducive to hay drying. Frequent precipitation is more damaging than the same amount of precipitation coming all at once.

### Heating and Forage Quality Losses

Heating may occur when bacteria, molds, and other microbes use some of sugars and starches in hay for their own growth and reproduction. Respiration causes a low amount of dry matter (DM) and nutrient loss to continue during hay storage (Wilkinson and Hall, 1966; Wood and Parker, 1971). Hay moisture is far below the 40% level, so plant enzymatic activity is very low (Honig, 1979). Minor heating occurs in dry hay stored under cover and DM loss over 6 months of storage is about 5% (Collins et al., 1987; Rotz and Abrams, 1988; Rotz et al., 1991c). Similar loss occurs with either large round bales or small bales stored in a shed (Collins et al., 1987). Hay stored outside and unprotected experiences additional loss of 10 to 15% in round bales from weathering of hay on the exposed surface.

Respiration reduces forage quality by removing some of the most digestible nutrients. This causes an increase in proportions of acid detergent fiber (ADF) and neutral detergent fiber (NDF) in the hay. Hay tonnage and quality decrease after storing in a stack. Anderson et al. (1981) studied the effect of weathering on hay quality (Table 7). Total crude protein content declines with time, but the concentration may increase due to the loss of soluble carbohydrates (sugar and starch) to the microbes. However, as microbial respiration heats the hay, the usable protein becomes much less because of the browning (Maillard) reaction. Severe browning reactions occur when mold growth heats the hay above 100 degrees F, and amino acids and sugars combine to form insoluble nitrogen forms. A by-product of heating is caramelization and production of a tobacco-like odor. Cows like the taste or aroma so they eat the forage well but are unable to utilize many of the nutrients.

**Table 7.** Forage quality of interior and exterior portions of alfalfa round bales stored outside. The ADF refers to acid detergent fiber and IVDDM refers to *in vitro* digestible dry matter. Source: Anderson et al. 1981.

| **Portions of bales** | **Crude protein** | **ADF** | **IVDDM** |
|---|---|---|---|
| | ---------------------- % of dry weight ---------------------- | | |
| Interior | 18.9 | 38.6 | 61.4 |
| Exterior | 19.4 | 45.8 | 46.9 |

## Hay Storage Recommendations

- Position uncovered stacks to take advantage of prevailing winds to blow snow off top bales and to dry them. A single row in a north-south position is usually best, but stacks should also be positioned up and down slope, or have a good drainage system.
- Allow at least three feet between stack rows. Stacks too close can become a trap for livestock.
- Separate stacks of 100 tons by at least 50 feet so that if fire starts the loss will be minimal. Check with your insurance company for their criteria on hay stack coverage.
- Stack yards should be well drained. An elevated rock pad of 1 to 3-inch rock is best.
- Mesh covering (net wrapping) of round bales will reduce the weathering effects on bales, stabilize the hay better than twine, but costs more than twine.

The best situation for marketing hay is to sell the hay in the field at its best quality and pass the storage and management costs on to the buyer. If a grower wants to speculate on a rising hay market, one must consider the added storage costs of dry matter and quality loss--and these are considerable.

## SUMMARY

- Storage results in dry matter losses, lowered forage quality, and reduced feed intake and utilization.
- The more valuable the hay, the easier it is to justify spending time and money to improve storage conditions.
- If barn or shed storage is not available, place stacks in sunny, breezy locations, on an elevated pad of rock, and cover stacks with tarps.
- Well-formed, tight bales, and the proper moisture content will minimize storage loss.

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