Hay Storage: Dry Matter Losses and Quality Changes

Introduction

Although cool-season annual forages are produced in Mississippi, hay is still a primary source of livestock feed during the winter. A solid understanding of how hay storage conditions affect hay losses and quality changes can help producers reduce feeding costs. Maintaining hay quality after harvest depends on proper storage. Total loss for high quality hay stored outside on the ground could be 25 percent to 30 percent, while losses for animal feeding could reach 40 percent. This dry matter (DM) loss from poorly stored hay also translates to significant dollar losses when lost nutrients have to be replaced by protein or energy products.

Factors Affecting Storage Losses

The amount of storage losses are directly related to several factors:

- moisture content at baling and the time of storage
- storage conditions (outdoor vs. indoor)
- environmental conditions (relative humidity, air temperature, and air movement), and
- forage species.

Hay that is baled at moisture contents greater than 20 percent can develop mold and lose dry matter and quality to bacterial degradation. In rare cases, hay baled at a high moisture content can spontaneously heat or combust. Moldy hay can be detrimental to livestock health.

The extent and duration of temperature rise in hay depends on moisture content. All hay baled at moisture contents between 15 and 20 percent will undergo some elevation in temperature in the first 2 to 3 weeks after baling. This heat buildup is referred to as "sweating" and is due to plant respiration and microbial activity. This temperature increase continues for up to 10 days. At a moisture level of about 30 percent, a bale may maintain a higher temperature for up to 40 days regardless of the forage species or bale shape. An electronic hay moisture and temperature probe that is 18 to 24 inches long can monitor these changes in moisture and temperature. The electronic probe can measure many samples quickly. At least 12 to 20 random samples are necessary to determine forage moisture accurately.

Heat generated by metabolic activity of the microorganisms and plant respiration will increase the temperature of hay (Fig. 1). Temperatures can range from 130 to 140 °F during the initial stage and decrease to 60 °F after 40 days. Equilibration usually occurs independently from moisture level. If temperature increase is no greater than 130 °F, then the hay should suffer no great reductions in hay dry matter and quality. However, during the sweat, measurable losses of 4 to 5 percent in hay DM may be recorded. Once stored hay has reached moisture equilibrium, there will be a 1 percent DM loss for every 1 percent loss in the original field baling moisture. For example, if hay was originally baled at 20 percent moisture and after 3 weeks reaches 12 percent moisture, there should be a corresponding 8 percent DM loss.

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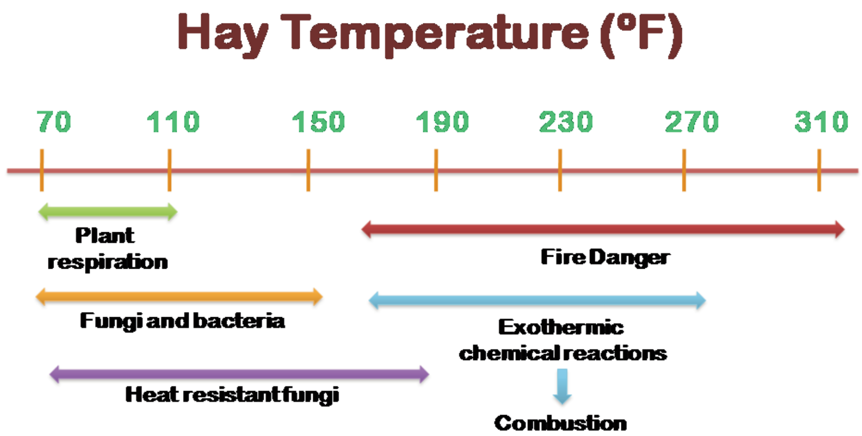

Figure 1. Hay heating causes and potential results.

Typically, as bale size and density increase, so does spontaneous heating. Though the amount of heat produced per unit of forage does not change, the more DM packed in the bale, the more difficult the heat dissipation. Due to the increase in spontaneous heating with the increase in density, it is recommended that square or rectangular bales be harvested at 20 percent moisture and large round bales harvested at 18 percent moisture. Combustion and fire can also occur if internal temperatures exceed 175 ºF due to oxidative reactions caused by protein breakdown. This type of oxidative reaction tends to occur 30 to 35 days after baling. Large round bales are more prone to oxidative reactions and combustion close to the bale surface, where oxygen concentration is higher. This is especially true if bale temperatures reach 340 ºF.

The temperature of hay that has been baled at high moisture content should be checked twice a day for 6 weeks after baling. The temperature inside a stack of hay can be determined using a commercial temperature probe or thermometer. One of the disadvantages of using a commercial temperature probe is that it is often too short to monitor the maximum interior temperature zone within a hay stack. A homemade thermometer can be made with a 10-foot piece of 3/4-inch diameter steel pipe. Drill eight 3/16-inch holes about 3 inches from the end of the pipe and then hammer the end of the pipe together to create a sharp edge for penetration (Fig. 2). Check the temperature in the center of the stacked hay. Do not walk directly on the stacked hay; instead use boards, plywood, or a ladder to spread body weight over a larger area and prevent falling into burned-out cavities. The easiest way to check the temperature is by inserting the pipe from the top of the stack into the innermost bales and lowering the thermometer to the end of the pipe using a

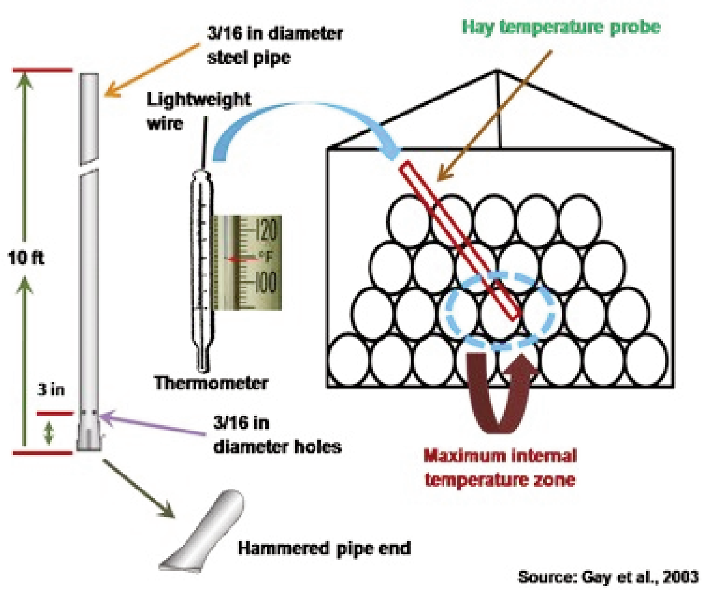

Figure 2. Homemade hay temperature probe and proper location for insertion.

Table 1. Recommendations for temperature changes in freshly cut hay bales stored in the barn.

Temperature (°F)	Monitoring Recommendations
< 130	Monitor temperatures in the hay stack twice a day.
130 to 150	Temperature may fluctuate. Check temperature every few hours.
150 to 175	Temperature will most likely increase; move hay out of the barn to provide air circulation and cooling. Monitor temperature every 2 hours.
>175	Fire is imminent or present. Contact the fire department immediately. Continue to monitor the temperature and do not attempt any put out any possible fires or move hay.

Source: Gay et al., 2003.

lightweight wire (Fig. 2). Retrieve the thermometer from the haystack after 10 to 15 minutes and read the temperature. If the temperature reading is 150 to 175 ºF, remove the hay bales from the barn immediately to increase air circulation and reduce the risk of fire. Continue monitoring the temperature every 2 or 3 hours (Table 1).

Where to Store Hay

Most Mississippi producers use large round bales, though square bales fit more efficiently into indoor storage space. It is important to store bales in a well-drained area. Most storage losses occur where hay bales touch soil. Place round bales on gravel, pallets, or tires to minimize dry matter losses (Table 2), but be aware that tires may hold water. Elevation is not necessary for bales covered in solid plastic because the plastic layer provides a barrier against moisture movement from the soil. Some studies have shown that these techniques reduce storage losses by 15 percent. These are the not the most recommended methods, but they are the ones most frequently used by producers with limited storage capacity. These methods are recommended only if the storage period is shorter than 90 days and daily temperatures are lower than 95 °F. In this case, use a tarp to protect hay from the weather, which reduces dry matter and hay quality. When using a tarp to cover hay bales, stack hay in a pyramid formation. Do not place the plastic underneath the bales because water could pool inside the tarp. Hay can also be stored in enclosed barns or roofed, open buildings, also called pole barns, but the cost of the structure can increase the cost of hay storage considerably. Initial cost of construction can range from about $2 to over $6 per square foot. Return on investment could take several years, depending on the

Table 2. Effect of storage method on percent dry matter (DM) loss from large round hay bales.

	Storage Period (months)	
Storage Method	0 to 9[1]	12 to 18
	% DM loss	
Ground		
Covered	5 to 10	10 to 15
Exposed	5 to 20	20 to 35+
Elevated (pallets/tires)		
Covered	2 to 4	5 to 10
Exposed	3 to 15	12 to 35
Enclosed barn	>2	2 to 5
Under roof (open building)	2 to 5	3 to 10

[1]If hay is used before spring warm-up.

Source: Huhnke, 2003.

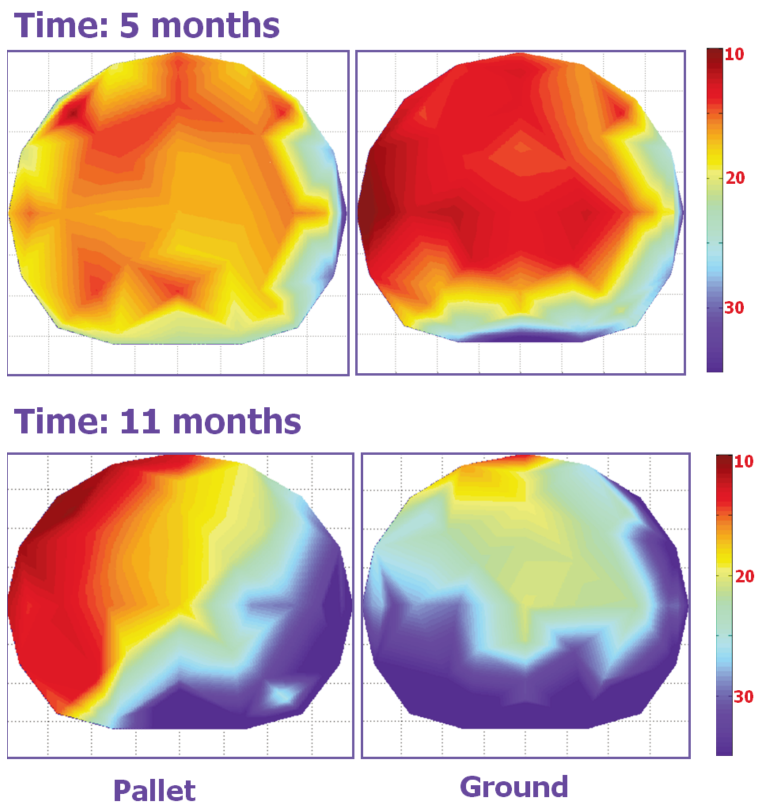

Figure 3. Moisture distribution on hay net wrapped and stored over time on a pallet or on the ground. Photo courtesy of K. Shinners, University of Wisconsin.

cost of the structure and hay prices.

When storing bales outside, maximize solar exposure to reduce moisture levels; avoid storing hay in shaded areas close to trees or buildings. Place bale rows in a north-south orientation so sun shines evenly over the bales from east to west. The flat ends of round bales should be butted together firmly to provide a barrier to precipitation. Allow at least 3 feet between bale rows for air circulation. Keep forage and weeds mowed between rows.

Hay stored outside and unprotected often exhibits excessive weathering and a decline in quality (Fig. 3). "Weathering" refers to the wet, discolored, frequently moldy layer on the exterior and bottom surfaces of round bales. This weathered hay is greatly reduced in quality and is often refused by livestock due to its very low palatability when whole bales are fed. The weathering process also decreases digestibility and increases fiber concentration. Storing these bales over a longer period of time has shown that up to 8 inches of the outer layer could be lost to weathering (Table 3). The depth of weathering depends on many factors, including the amount of rainfall during the storage period, condition when hay is baled, bale shape, and bale density.

Dry matter (DM) loss is affected by hay moisture, temperature, and exposure to weather. To maintain as much hay quality as possible, store it immediately and properly. Plan investments in storage facilities carefully to yield returns within the desired time frame. Low-cost storage systems such as elevating the bales and covering them with tarps could be used in the short term to offset costs and losses. These are ways to reduce loss in hay dry matter and quality:

- ensure that hay is properly cured (less than 15 percent moisture)
- protect the bales from rain and other weather elements
- allow room for proper ventilation and air circulation
- elevate hay from ground, and
- check hay for mold and increasing heat.

Hay Preservatives

Hay preservatives work by chemically inhibiting or killing microorganisms that can spoil hay baled at more than 20 percent moisture. Applying salt (sodium diacetate) has been a common practice in the past to prevent mold and spontaneous heating, but the amount of salt needed for high-moisture hay could be sizeable and expensive. In some instances, large amounts of salt could decrease forage palatability. Urea, anhydrous ammonia, and other chemicals are

Table 6. Estimated cost of hay after storage losses for different round bale sizes.

Outer layer depth (inches)	Bale size (ft)[1] 4 x 4	5 x 4	6 x 5	7 x 6	8 x 6
	——— % DM loss ———				
2	16	13	11	9	8
4	31	25	21	18	16
6	44	36	31	27	23
8	56	46	40	34	31

[1]Bale size = diameter x width.
Source: Huhnke, 2003

known to be effective in preserving moist hay if applied in sufficient quantities. Organic acids such as proprionic-acetic acid, ammonium proprionate, and pure proprionic acid have been used to reduce dry matter losses and maintain forage quality.

Determining moisture content of hay is essential because application rates of preservatives depend on bale moisture (Table 4). Anhydrous ammonia is an effective preservative for hay containing less than 30 percent moisture. It should be applied at a rate of 1 percent, or 20 pounds anhydrous ammonia per ton of wet hay. Applying anhydrous ammonia is difficult. Urea can be used instead. Using organic acids is less common because of its cost and application methods. Organic acids are volatile and can corrode farm equipment. Ammonium proprionate is a buffered proprionic acid material that is less volatile and less corrosive. Before making decisions about hay preservatives, evaluate the economic value of hay and read the application recommendations on the preservative's label.

Feeding Losses

Hay losses also occur during feeding and can be a major expense in livestock operations. Hay losses are greatest when several days' worth of hay is fed at one time. Feeding a one-day supply of hay each day minimizes waste but increases labor costs. Most Mississippi livestock producers feed large round bales. When feeding large round bales without a ring or rack, a good way to estimate how many bales to have available each day is to figure one mature beef animal per foot of outside diameter of the bale. Even then, feeding losses can be excessive.

Although feeding losses cannot be eliminated, there are ways to reduce the amount of hay lost. Using hay feeders such as cone, ring, trailer and cradle feeders can reduce losses by preventing cattle from trampling or bedding down in hay (Fig. 4). Cone feeders are the most feed-efficient type, but many producers use ring feeders instead because they are less expensive.

Hay losses with ring feeders are usually low, even if a 7-day supply of hay is fed at one time. Most hay rings have enough space for approximately ten cows at a time. To make the most efficient use of hay rings, purchase several rings and feed multiple bales at one time based on herd numbers. Feeding hay in these feeders could be crucial for producers who do not feed hay to their livestock on a daily basis.

Producers may decide to unroll or chop the bale and feed it on the ground as loose hay or deposit it in a windrow for feeding. These feeding methods are labor intensive and can result in high trampling and soiling losses if too much hay is fed at one time. If a 3-day day supply is unrolled or chopped, feeding losses could be up to 40 percent or more. If fed on a daily basis, feeding losses could be reduced to 12 percent. One advantage of this system is that feeding areas vary, allowing for better manure and nutrient distribution. Feeding in areas with thin, poor soil is ideal in this case because manure builds hummus and mineral deposits in the soil.

Feeding management can also reduce hay waste.

Table 4. Recommended rates for applying organic acid preservatives (proprionic and propionic-acetic) based on bale moisture.

Hay Moisture (%)	Application Rate (% dry weight)	Amount (pounds per ton)
20 to 24	0.5	10
25 to 29	1.0	20
30 to 35	1.5	30

Sources: Henning and Wheaton, 1993; Riddell et al., 1980.

Producers should provide only the amount of hay that will be consumed by the herd in a short time. It is also advisable to wait until the animals have eaten nearly all of the hay in the feeder before moving the feeder to a different location or providing more hay. Hay feeding location can be important. It is important to keep feeders out of the mud because, while animals may eat hay dropped on dry ground, they will not eat hay caked in mud. Place hay feeders in well-drained areas and move them regularly. Otherwise, feeders may become damaged or difficult to move. Be careful not to damage feeders when handling or loading them with farm equipment.

Using permanent feeding pads is a good way to keep feeding areas dry. Pads can be created with crushed gravel or even concrete. Another option is to move hay-feeding areas around the ranch to minimize the damage to any specific area of the pasture. Start feeding hay at the far side of a paddock and move hay-feeding areas towards the paddock entrance as the feeding season progresses.

Harvest and Storage Effects on Hay Quality

Many changes in forage quality are related to spontaneous heating. Sugars are the primary plant carbohydrates lost during storage respiration. During extended storage periods, microbial and fungal respiration reduce oxygen levels and produce carbon dioxide, water, and heat, causing the reduction in DM. Dry matter losses could exceed 10 percent if moisture levels are between 20 and 30 percent (Table 5). Because of their lower carbohydrate concentrations, perennial warm-season grasses may lose less dry matter than legumes or other cool-season grasses. Concentrations of total nonstructural carbohydrates (TNC) usually decrease depending on the storage conditions. Larger losses of TNC usually occur within 10 days of baling, when most of the spontaneous heating occurs and microbial activity is a higher rate.

Subsequently, TNCs are reduced during storage, while neutral detergent fiber (NDF) and acid detergent fiber (ADF) fractions in the hay increase. These changes in forage composition reduce hay palatability, digestibility, and quality. Fiber concentrations usually increase along with spontaneous heating, with the largest changes occurring during the first 12 days of hay storage. Temperatures below 120 ºF generally do not change digestibility, but temperatures above 140 ºF decrease digestibility by 14 percent. Crude protein (CP) concentration has been reported to increase due to the high TNC oxidation process during the first 50 to 60 days of hay storage. This increase in protein concentration is temporary, and under long-term storage, CP concentration is expected to decrease 0.25 percent per month due to the volatilization process. Because of oxidation, the weathered hay layer usually has lower CP and higher NDF and ADF than the deeper hay layer.

Economic Impact of Hay Losses in Livestock Feeding

Some producers might think that hay losses are unimportant, but hay losses can add up to significant amounts of money, especially where drought affects available forage and hay prices (Tables 6 and 7).

Average hay storage and feeding losses could account for over 10 percent of livestock production costs. Producers often do not realize how large hay losses are or how easy and inexpensive it can be to reduce losses. Here's an example: assume that a rancher has a herd of 30 cows, and their average weight is 1,200 pounds. Each cow consumes 2 percent of its body weight per day, on average, for 180 days during the winter. The rancher will need 72 tons of hay dry

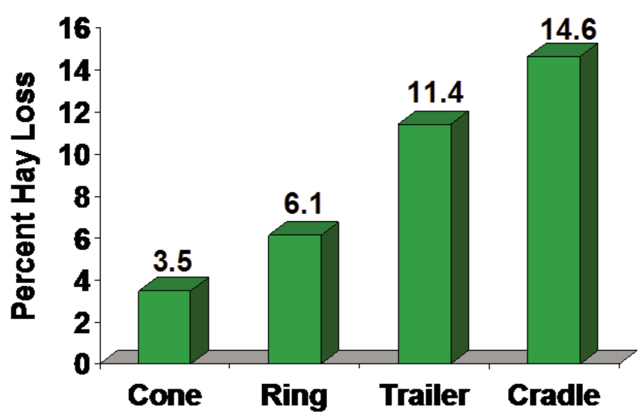

Figure 4. Percent hay loss by utilizing different feeder types.
Source: Buskirk et al., 2003.

Table 5. Dry matter and quality loss (% of the initial forage yield) at different hay storage moisture levels.

Storage Moisture	Dry Matter Loss	Digestible Dry Matter Loss	Crude Protein Loss
	%		
11 to 20	4.5	6.2	6.0
20 to 25	7.9	11.8	8.8
25 to 34	10.9	13.5	7.5

Source: Wilcke et al., 1999.

matter. Assume 85 percent dry matter. In numerals, this equation looks like this: (30*1200*0.02*180)/2000 = 64.8/0.85 = 76. If the hay is properly stored in the barn and storage loss is 5 percent, then approximately 77 tons of hay will need to be harvested or purchased (76/0.95 = 77.0). If, however, round bales are left exposed outside on the ground, resulting in a 35 percent storage loss, then the rancher will need 117 tons of hay. This is an additional 40 tons of hay harvested or purchased, or 40 acres of hay for a typical harvest rate of 1 ton/ac/cut yield. On average, it might cost $30 to $40 per acre to mow, condition, rake, and bale hay. Hay may cost $80 to $105 per ton to purchase. In other words, storing hay on the ground instead of in a barn can have substantial economic consequences. If the producer is harvesting hay, the additional cost is $1200 to $1600 per year for the 30-head herd; buying hay can bring the additional cost to $3120 to $4095.

Dry matter loss from poorly stored hay also translates to loss in forage quality. For example, consider a 5′ x 4′ bale of bermudagrass hay weighing 1000 pounds that is stored outside, on the ground, and uncovered. There are 50 bales in the lot. The 4-inch outside layer has been degraded and represents a 30 percent dry matter loss. This means a 300 pound loss per each 1000 pound bale. The bermudagrass originally contained 10 percent protein and 58 percent total digestible nutrients (TDN). Forage quality loss amounts to 30 pounds of protein and 174 pounds of TDN. To replace the TDN lost with pelleted corn gluten feed at a cost of $9.00 per CWT, the replacement cost is $15.66 per bale of TDN. Replacing protein losses using soybean meal at $18.00 CWT will cost $5.40 per bale. Due to these losses, additional hay must be purchased to replace losses from storage and feeding. Together this translates to losses of $5 to $8 per bale ($250 to $400 per lot) when hay is improperly stored outside.

Summary

Storage losses affect the cost of hay even if it is produced on the farm. In Mississippi, unprotected round bales stored outside could lose 50 to 60 percent of their feed value due to longer microbial activity (mild winter temperatures) and high precipitation. Assuming that weathered hay is lost because it is not consumed by livestock, the cost per ton of hay actually consumed increases proportionally with the increase in weathering. Production costs for good quality hay could be high depending on yields, production inputs, and other factors. Dry matter loss is a direct result of microbial activity and improper storage practices. The extent of weathering damage that occurs with hay stored outside varies with climatic factors, forage species, and bale diameter. Half of the outside storage losses occur at the bale/soil interface due to the bale drawing moisture from the soil.

During microbial activity, the soluble carbohydrates in the hay are consumed. The amount of dry matter loss is directly related to heat generation, which in turn is related to moisture content. Highly digestible soluble carbohydrates decline in weathered hay, resulting in higher ADF concentration and lower digestibility. Total crude protein declines if hay undergoes excessive heating and weathering. As baling moisture rises, the amount of storage dry matter loss increases. This dry matter loss results in less feed and lower quality feed. Trade-offs occur between storage losses and harvest losses, but in general, hay baled at 15 to 18 percent moisture will maximize the overall nutrient yield.

Table 6. Estimated cost of hay after storage losses for different round bale sizes.

	Bale Size (ft)[1]		
Average Depth of Weathered Layer (inches)	4 x 4	5 x 4	6 x 6
	$ per ton		
2	116[2]	113	111
4	131	125	121
6	144	136	131
8	156	146	140

[1]Bale size = diameter x width.

[2]Assumes a production cost of $100 per ton.

Table 7. Economics of hay storage losses.

	Storage loss (%)[1]							
	5	10	15	20	25	30	25	40
Hay Price (per ton)	Economic loss ($ per ton hay)							
40	2	4	6	8	10	12	14	16
60	3	6	9	12	15	18	21	24
80	4	8	12	16	20	24	28	32
100	5	10	15	20	25	30	35	40
120	6	12	18	24	30	36	42	48

[1]Loss percentage does not include losses associated with shrinkage or reduced forage quality.

Source: Huhnke, 2003.

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