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Round Bale Hay Storage in Kentucky

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Introduction

Most of the hay produced in Kentucky for feeding livestock is packaged as large round bales. Large package sizes and rapid baling rates minimize labor requirements for baling and transport around the farm (local). However, storage losses of round bales are frequently much greater than those of similar hay in smaller rectangular bales. Most of the increased storage loss for round bales appears to result from storage outside without protection from the weather.

Losses during outside storage of twine-tied round bales result from weathering and from moisture movement from the ground into the bale. Weathering is visually associated with a change in color and deterioration of the outer layers of hay following exposure to rainfall, sunlight, and other factors during storage. Weathered hay suffers substantial losses of both yield and forage quality and is much less palatable to livestock than undamaged hay.

Hay Changes after Baling

Heating

All hay baled at moisture contents above 15 percent will undergo some elevation in temperature in the first two to three weeks following baling. This heating is referred to as "sweating" or "going through a sweat" and is due to plant respiration and microbial activity. Even relatively dry hay (15 to 20 percent moisture content) will heat enough to cause measurable dry matter losses (4 to 5 percent). A small amount of heating (up to 130°F) does no real damage to hay quality but serves to dry out the hay by evaporating some of the moisture it contains. Under Kentucky conditions, hay will generally reach an equilibrium moisture content near 15 percent.

When moisture contents of hay are greater than 15 percent at baling, some changes in hay color occur along with microbial growth and heating. The green color of moist baled hay typically changes to various shades of brown, depending on the extent of heating (Table 1).

In general, some loss in dry matter and quality is associated with these changes initially occurring after baling. A rule-of thumb useful in estimating yield loss of round bale hay is that 1 percent of original yield will be lost for each 1 percent moisture that is lost as stored hay reaches its equilibrium storage moisture. For example, if hay is baled at 20 percent moisture and then dries to 14 percent during storage, it will suffer a dry matter yield loss of about 6 percent.

Baling above 20 percent moisture without taking steps to reduce the microbial activity responsible for this heating may result in substantial quality loss. The extent of fungal growth during hay storage is a function of moisture content. Under normal conditions, the evaporation of water helps to dissipate heat generated by microbial growth on moist hay. The extent of heat damage can be assessed by looking at the color change during hay storage. Heating of moist hay causes a chemical reaction that fuses plant sugar and amino acids into an indigestible product called the Maillard product. Protein bound up in this process is called heat-damaged protein and is unavailable for animals. When hay heats sufficiently to cause a very dark brown to black color, its protein may be nearly indigestible.

Table 1. Effect of Moisture Content at Baling on Dry Matter Loss and Quality Changes during Storage.

% Moisture	% DM Loss	Quality Changes
≤15	None	None
15-20	1-5*	Loss of moisture, slight loss of digestibility or energy (less than 5 percentage units).
>20	5+	Significant loss of digestibility (more than 5 percentage units), extensive loss of green color, lower protein digestibility due to heat-damaged protein.

* Dry matter losses in storage are approximately equal to baling % moisture minus equilibrium % moisture (about 15% in Kentucky).

Since heat movement in dry hay is slower than in moist hay, the movement of heat from the center to the outside of the bale slows down as the surface layers begin to dry. This causes the internal bale temperatures to increase rapidly after much of the surface moisture appears to have been removed. This can cause hay to catch fire due to spontaneous combustion if respiration and microbial heating raise temperatures greater than 170°F. However, when spontaneous combustion occurs, it does not originate in the center of the round bale, but nearer the outside, because oxygen levels in the middle of the bale are usually too low for combustion to occur.

Dustiness in moist hay following storage consists largely of fungal spores produced during this microbial growth. Although numerous bacteria are present in hay, fungi account for most of the microbial growth during hay storage. Mold spores contribute to colic in horses and are responsible for significant economic losses to this important Kentucky livestock industry. Breathing spores of the fungus *Aspergillus fumigatus* during the handling of moldy hay can cause farmer's lung, a sometimes debilitating disease in which the fungus grows in human lung tissue. Hay with a significant amount of mold and mold spores can be used in cattle rations because cattle are less sensitive.

Baling Moisture Guidelines

Package size and density affect hay during storage. The larger volume and greater density of large round bale packages compared with small rectangular bales result in a greater likelihood for significant heating at a given moisture level. In University of Kentucky research, round bales of alfalfa had twice the heat-damaged protein compared with small rectangular bales when both were baled at 25 percent moisture. Although 20 percent moisture or less is considered to be safe for baling small rectangular bales without fear of heat damage, we recommend a target moisture of 18 percent or less for dependable storage of round bales.

Package Type and Size Effects

Bale Size and Hay Loss

Alfalfa storage research indicates that increased size and densities of round bales increase heat-damaged protein and fiber concentrations compared with rectangular bales, possibly due to restricted heat and moisture exchange. Figure 1 illustrates the difference in heat-damaged protein between round and rectangular bales of alfalfa for the same moisture range (Collins et al., 1987).

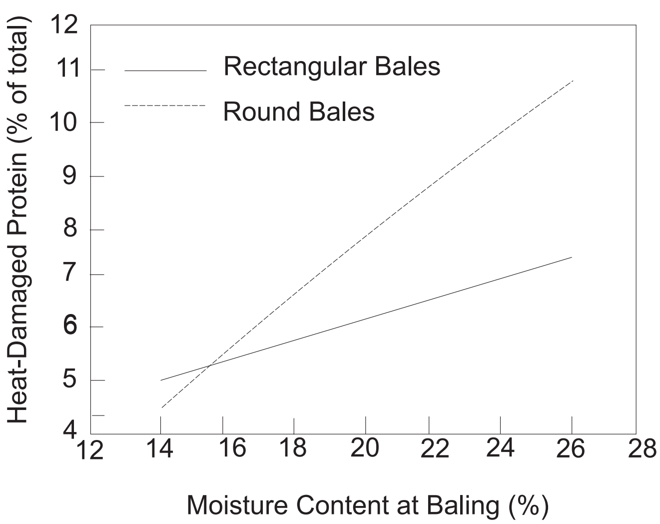

Figure 1. Effects of Alfalfa hay package type and moisture at baling on heat-damaged protein.

Due to the cylindrical shape of round bales, even a seemingly insignificant layer of weathered material on the bale surface can represent a substantial loss of yield and quality based on the total volume of hay affected. A 2-inch layer of weathered material on the bale surface represents 16 percent of the bale volume of a 4 foot by 4 foot bale even though less than 7 percent of the bale diameter is affected (Table 2). This calculation does not include the ends of the bale since little loss occurs there. This relation between weathering depth and the proportion of the total volume affected results from the cylindrical shape of round bales. If weathering extends only 4 inches into a 5 foot by 4 foot bale, one-fourth of the total hay in the package has been damaged. Larger round bales lose relatively less with a given weathering depth than smaller-sized packages.

Table 2. Percentage of Bale Volume Affected.

Bale Dimensions		Depth of Weathered Layer in Inches			
Diameter	Width	2	4	6	8
		% of bale volume weathered			
4'	4'	16	31	44	56
5'	4'	13	25	36	46
6'	5'	11	21	31	40

Hay Storage Options

Outside on Ground

Round bales placed outside on the ground represent the cheapest method of hay storage with the greatest dry matter weathering loss potential (Table 3). Much of the yield loss that occurs during outside storage takes place on the bottom of the bale where moisture levels remain highest and air movement is the lowest. Outside storage losses can be reduced by as much as 38 percent by selecting a well-drained site and using poles, pallets, tires, crushed rock, or other materials to break the contact with the wet soil and to provide some air space between the bottom of the bale and the soil surface. Round bales should also be packaged tight enough to maintain uniform shape and minimize contact with the soil surface. They should be placed with sufficient space between bales to allow air flow and prevent collection of water.

Plastic Wrap

In recent years, new technologies have been developed that attempt to reduce outside storage losses by covering the circumference of round bales with solid plastic sheeting to shed water. Past research has demonstrated that wrapping the round bale surface with ultraviolet (UV) light-stabilized plastic can reduce dry matter yield losses to only 7 percent compared with 35 percent losses from unwrapped bales stored outside on the ground. Solid plastic wrap can be applied at baling with the proper attachments to late model balers. Wrapping during baling avoids the additional labor needed with bale bonnets or sleeves. No twine is needed with self-adhesive plastic wrap, thereby offsetting a portion of the cost. Wrapping with stretch plastic costs approximately $1.50 per 1,000 pound bale, or $3 per ton.

Table 3. Comparison of Storage System Life, Approximate Cost per 1,000-pound Bale, and Dry Matter Loss.

Storage System	System Life	Approx. Cost	Dry Matter Loss
	Years	$/bale/yr	%
Conventional shed	20	5.00	4-7
Pole structure with plastic roof on pad	4	3.00	4-7
Reusable tarp on pad*	5	3.00	4-7
Bale sleeve on ground	1	3.00	4-7
Plastic wrap on ground	1	1.50	4-7
Elevated stack on pad (rock plus filter fabric)	20	2.62	13-17
Net wrap on ground	1	1.50	15-25
Stacked on ground (cost is twine)	1	0.75	25-35

*Bales are stacked.

Net Wrap

Net wraps are porous materials designed to shed water and permit greater air flow at the bale surface at less cost than plastic wraps. Like plastic wraps, net wraps can be applied during baling and eliminate the need for twine. Studies comparing yield loss between various storage methods indicate that net wrap is somewhat intermediate between twine-tied outside bales and plastic wrap (Table 3). University of Kentucky research shows that net wrap reduces tall fescue dry matter losses by 32 percent compared with bales stored outside on the ground.

Temporary Structures for Reusable Storage

Plastic-covered Post-frame Structures: University of Kentucky research has found that effective, low-cost structures can be built to store large round bales of hay. These structures consist of a center row of posts supporting rafters spanning a width of roughly 28 feet. The length of such a structure is determined by the number of bales to be stored. One “bay” would need to be twice the length of the bales for most efficient storage. The roofing material would consist of a spun-bonded polypropylene with a black waterproof coating. A floor or base impermeable to water should be installed to prevent wicking of moisture from the ground into stored hay. One option would be a filter fabric and rock base costing approximately $0.40 per square foot. Total investment cost for the structure plus rock/filter fabric floor is approximately $1.15 per square foot.

Reusable Tarps or Bale Coverings

Another option for improved bale storage is the reusable heavy-duty tarp. These covers should be durable enough to last five to seven years, should be treated to avoid photodegradation by UV light, and should have some method to distribute the strain of tie-downs across the length of the stack. Bales should be stacked as high as is practical and safe, usually in a 3-2-1 pyramid design with three bales in the bottom layer, two in the second layer, and one on top. This requires a front-end loader for stacking but minimizes the size of the tarp needed relative to the tons of hay stored.

Another bale arrangement that does not require a loader attachment is a 3-2 pyramid. This design lacks the natural peak that would more effectively shed water. Therefore, stacks of bales would need to be placed on a slope running the direction of the length of the stack so that water would drain off the end of the tarp. This design reduces storage capacity by 17 percent compared with the 3-2-1 stack but would require a slightly smaller tarp. An alternative solution is to place square bales in the middle of the upper layer to construct a middle peak to the stack, but the cost and trouble of the extra labor would have to be considered.

Some type of ground flooring under these reusable tarps is also desirable. University of Kentucky research indicates that approximately one-half of the storage losses in large round bales comes from direct contact with the ground.

Bale Sleeves

Bale sleeves offer another method for protecting the round bale surface and are added to twine-tied bales before placement in the round bale storage area. Storage losses are similar to those sustained with plastic wraps and inside storage. However, the material cost per ton is usually greater than plastic or net wraps, and additional labor is required to move and place bales in the sleeve. The need for twine in addition to the wrap also adds to the cost per ton. Bales must be sized correctly for the sleeves, a difficult process when trying to get a tight fit. Plastic, net wraps, and bale sleeves are not reusable; therefore, proper disposal is required.

Permanent Hay Storage Structures

Numerous options are also available for permanent hay storage structures. Construction costs for such buildings range between $2 and $4 per square foot of floor space. Dimensions should be based on the size of bales to be stored, and at least 2 feet of clearance above the tallest stack is needed. Many designs accommodate three layers of bales.

Using a typical design as an example, and including depreciation, taxes, and other costs, a permanent hay storage structure would cost about $10 per ton of storage capacity per year.

Storage Options and Hay Quality

Digestibility and Fiber Levels

Weathering reduces the quality of round bale hay (Table 4). Most of the negative effects of outside storage on the quality of round-baled hay are seen in the weathered portion of the same bale, with minimal change in quality of unweathered hay from the bale interior. Indiana research showed that hay from bale interiors did not change in *in-vitro* dry matter disappearance (IVDMD) during storage, but hay from the weathered layer on the bale surface declined sharply to 36.8 percent after a five-month storage period (Table 4). Digestibility was approximately 59 percent for the unweathered portion of grass round bales from the interior portion of the bale compared with less than 43 percent digestibility for weathered material from the same bales.

Table 4. Quality of Weathered and Unweathered Portions of Grass and Grass-alfalfa Hay in Round Bales (Lechtenberg et al., 1979).

Hay Type	Bale Portion	Digestibility	Crude Protein	Acid Detergent Fiber
		-------------%-------------		
Grass	Unweathered	58.8	13.5	44.4
Grass	Weathered	42.5	16.4	49.4
Grass-legume	Unweathered	56.5	14.3	45.0
Grass-legume	Weathered	34.2	16.9	48.7

Weathered hay is poor in quality because soluble carbohydrates in the outer layer of hay are both leached out by moisture and consumed by microbial growth. Increased fiber concentrations reduce livestock intake levels because fibrous constituents are used more slowly in the rumen compared with nonfiber components of the forage. Research at the University of Kentucky shows that even relatively low-quality hay is negatively affected by unprotected outside storage (Figure 2; Collins et al., 1995). Researchers compared the digestibility of hay from round bales of June-cut fescue stored for about one year using a variety of methods. Hay samples taken from the interior of all storage methods had similar digestibility values, approximately 50 percent. This indicates that the portion of hay protected from the weather retained its quality. However, samples taken from the outside surfaces of bales exposed to the weather were drastically reduced in digestibility. Although net wrap provided some protection from weathering, it did not prevent loss in quality of weathered hay. Bales stored inside, or tied using solid plastic wrap and stored, showed little or no loss of digestibility.

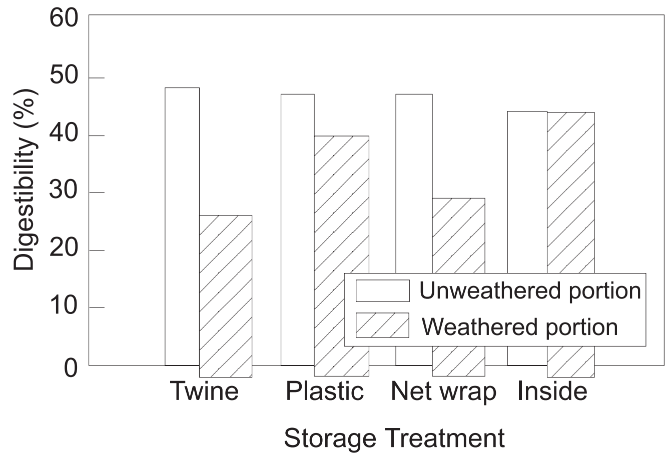

Figure 2. Digestibility of tall fescue hay in round bales stored outside using different binding materials or inside.

Protein

Of the quality constituents routinely measured during hay storage, crude protein concentration is least affected by outside storage conditions. Analysis of weathered hay often shows a slight increase in protein concentration compared with unweathered hay from the same bales. Increased protein concentration can result because protein is lost at a slower rate than that of some other forage constituents, such as carbohydrates, and such water-soluble minerals as potassium. However, research also has shown that the protein in weathered hay is used less efficiently than protein from undamaged hay. Crude protein analysis alone does not provide a very accurate reflection of the impact of storage on hay quality.

Species Differences

Legume forage is more susceptible to losses during outside storage than grass hay because legume hays, such as alfalfa and red clover, contain more water-soluble constituents that are most susceptible to loss during weathering. Indiana research shows much greater losses of digestibility in weathered hay from grass/legume-mixed hay than from grass bales (Table 4). Digestibility fell to 34 percent in weathered grass/legume-mixed hay compared with 43 percent in similarly treated grass hay. These data suggest pure legume hay or grass/legume-mixed hay with a high proportion of legume is preferred for inside storage or for outside storage options that offer protection from the weather.

Round Bale Storage Economics

To evaluate the economics of round bale storage, it is important to compare the cost and the estimated life of the storage structure or method and its value in terms of hay value saved. The cheapest storage is not always the best solution, unless hay is extremely poor in quality and low in value.

Tables 5, 6, and 7 show a comparison of several methods of storage of 100 tons of 5-foot by 4-foot round bales weighing 1,000 pounds each. The final calculations are made for two types of hay: 1) alfalfa hay valued at $85/ton, and 2) grass hay valued at $40 per ton. Table 5 indicates the assumptions used for the economic analysis of investment costs for each system. Table 6 specifies the projected annual costs for depreciation, interest, repairs, taxes, and insurance for each storage option.

The value of each storage system relative to outside storage on the ground is estimated in Table 7 for grass hay and alfalfa hay valued at $40 and $85 per ton, respectively. Values for dry matter losses for each storage system were based on the value of the hay. These figures were compared with the losses of the same hay stored outside on the ground with no weather protection (stack on ground option). These differences are expressed as "Savings over Stack on Ground."

In all but one case (conventional shed and $40 per ton grass hay), improved bale storage resulted in sufficient savings to cover all costs associated with the storage system employed. The savings in $40 per ton grass stored in a conventional shed was only $0.27 per ton short of covering all costs for constructing the shed.

Table 5. Investment Costs in Six Potential Hay Storage Options.

Storage System	Unit Cost ($/sq ft)	Unit Cost ($/ton)	Cost $ for 100-Ton Capacity	Life Years	Salvage Value
Conventional shed	3.50	78.97	7897.00	20	0
Pole structure with plastic roof on pad	1.20	37.33	3733.00	20	0
	0.12	3.73	373.00	4	0
Reusable tarp on pad*	0.73	17.60	1760.00	4	0
Bale sleeve on ground	0.15	6.00	600.00	1	0
Plastic wrap on ground	0.08	3.00	300.00	1	0
Elevated stack on pad	0.40	18.67	1867.00	20	0
Net wrap on ground	0.08	3.00	300.00	1	0
Twine-tied on ground	0.04	1.50	150.00	1	0

* Bales are stacked two high in a 3-2 pyramid; no front end loader is required.

Table 6. Annual Costs of Depreciation, Interest, and RTI (Repairs, Taxes, and Insurance) for Each System.

Storage System	Depreciation	Interest*	RTI %	RTI	Annual Cost	Cost per ton
Conventional shed	394.85	394.85	3	236.91	1026.61	10.27
Pole structure† with plastic roof on pad	186.65	186.65	4	149.32	522.62	5.23
	93.25	18.65	2	7.46	119.36	1.19
Reusable tarp on pad	440.00	88.00	3	52.80	580.80	5.81
Bale sleeve on ground	600.00	30.00	1	6.00	636.00	6.36
Plastic wrap on ground	300.00	15.00	0	0.00	315.00	3.15
Elevated stack on pad	93.35	93.35	1	3.00	189.70	1.90
Net wrap on ground	300.00	15.00	0	0.00	315.00	3.15
Twine-tied on ground	150.00	7.50	0	0.00	157.50	1.58

*Interest rate of 10 percent on the average value of the system (Beginning value minus ending value divided by life of system or structure).

† Note: Total cost of plastic-covered structure is sum of these two rows.

Table 7. Total Annual Costs for Each System, Including Dry Matter (DM) Losses, on a Per Ton Basis.

Storage System	DM Loss*	System Cost	Grass Hay: Hay Value	Grass Hay: DM Loss	Grass Hay: DM Savings over Stack on Ground	Alfalfa Hay: Hay Value	Alfalfa Hay: DM Loss	Alfalfa Hay: DM Savings over Stack on Ground
	%		....$/ton					....
Conventional shed	5	10.27	40.00	2.00	10.00	85.00	4.25	21.25
Pole structure with plastic roof on pad	7	6.42	40.00	2.80	9.20	85.00	5.95	19.55
Reusable tarp on pad	7	5.81	40.00	2.80	9.20	85.00	5.95	19.55
Bale sleeve on ground	8	6.36	40.00	3.20	8.80	85.00	6.80	18.70
Plastic wrap on ground	5	3.15	40.00	2.00	10.00	85.00	4.25	21.25
Elevated stack on pad	10	1.90	40.00	4.00	8.00	85.00	8.50	17.00
Net wrap on ground	23	3.15	40.00	9.20	2.80	85.00	19.55	5.95
Stack on ground	30	1.58	40.00	12.00	0.00	85.00	25.50	0.00

* The weight of the weathered layer is considered part of the total dry matter loss.

Summary

Several round bale storage options are available for Kentucky farmers. The hay savings from these methods will vary according to the method and the value of the hay. Economic analysis of hay storage options indicated that improved bale storage options will pay for nearly any bale storage system.

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