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HAY PRESERVATION

Craig C. Sheaffer and Neal P. Martin*

Minnesota farmers harvest about 9 million tons of hay annually, but large losses in quality and quantity occur. Field operations involved in hay making must be timed carefully to preserve forage quality. Cutting must be done at the optimum stage of maturity and when two or three drying days are expected. Hay should be raked when it is moist enough to avoid leaf shattering, but dry enough to store properly. The problems of unpredictable growth conditions and curing weather plus the difficulty of determining hay moisture make hay production one of the most difficult farm operations to manage.

This publication will examine the management alternatives available to producers for preserving quality hay with emphasis on the role of hay preservatives.

Losses During Field Curing of Hay

Cut forage plants continue to respire until their moisture content falls below 40 percent. Research indicates this respiration of readily digestible carbohydrates consumes 2 to 16 percent dry matter, the greatest losses occurring during poor drying conditions.

As hay dries, the leaves become brittle and are easily shattered by mechanical manipulation. Hay making losses during field operations are as high as 15 to 30 percent of total dry matter. These losses increase as harvest moisture levels decrease and the number of hay handling operations increases. Initial losses in dry matter occur during cutting and conditioning, with values of 1 to 6 and 1 to 4 percent for cutting and conditioning processes, respectively. Raking is the most detrimental field operation with losses from 5 to 15 percent. Baling losses can contribute an additional 1 to 15 percent, depending on equipment type. Conventional rectangular baler losses range from 3 to 8 percent.

Field dry matter losses from undried windrowed hay increase 3.5 percent per inch of rain. Rainfall-induced losses are greater for drier hay. Often rain-soaked hay must be reraked, which further increases leaf losses. Rain causes leaching of nutrients and increases loss due to respiration. In research at Purdue University, one inch of artificial rain on field-cured hay reduced TDN content 5 percentage points and TDN yield 200 lb/A. At a cost of $.05 per lb. of TDN, rain damage reduced hay value $11 per ton. Hay drying time can be reduced by conditioning, thereby reducing risk of weather damage, but nutrient leaching losses due to rain are greater for crimped or crushed hay.

In addition to dry matter losses as a result of mechanical operations and rain damage, delaying the cutting and harvesting of a crop due to inclement weather results in the disruption of cutting schedules and labor allocations. In extreme cases only two cuttings may be possible instead of three, which reduces seasonal forage yield. Delays in forage cutting from the optimum developmental stage are detrimental to quality. Alfalfa digestibility (TDN) declines .5 percentage points per day following flowering.

Losses During Storage of Hay

Stored hay may lose 5 to 10 percent dry matter when stored below 20 percent moisture. Hay dry matter losses during storage are related to microbial growth and to a subsequent

*Assistant professor and extension agronomist and associate professor, respectively, Department of Agronomy and Plant Genetics.

heat build-up. Heating will occur to some extent in all forage material unless it contains less than 15 percent moisture. The extent of temperature rise and duration of heat production in hay depends on moisture content. A relative humidity of 90 to 100 percent, which favors mold development, can develop in 20 percent moisture hay that is stored inside. The heat generated by the metabolic activity of the microorganisms and plant respiration increase the temperature of hay (Figure 1). Heat resistant fungi are active when the temperature is between 113 and 150° F.

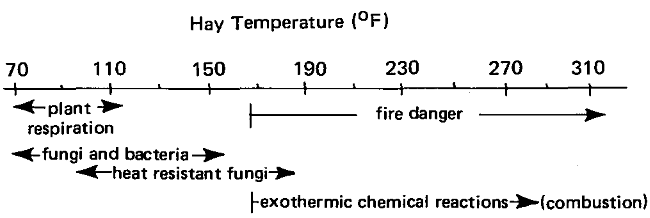

Figure 1. Causative agents in the heating of hay.

A large variety and number of microorganisms are associated with plant material in the field, but fungi are the microbes primarily responsible for breakdown of complex carbohydrates. Heating above 175° F results in thermal death of microbes; then heat-producing chemical reactions serve to further increase temperatures. A subsequent rapid oxidation of reactive compounds may cause a further temperature rise to an ignition point of 448 to 527° F. If enough oxygen is present, flames will erupt. The time required for heating to combustion may vary from 4 to 10 weeks, depending on storage and climatic conditions and on the moisture content of the forage.

Moisture levels for safe storage of all hay types have not been defined, but for baled hay a moisture content of 25 percent or less greatly reduces mold growth and the risk of spontaneous combustion.

The obvious consequence of spontaneous heating of forages is combustion, which has resulted in numerous barn and silo fires. But molding of forages and heating to temperatures below ignition also result in serious losses of forage quality and quantity. Available carbohydrate and protein portions of forages are reduced. Carbohydrates are used in microbial metabolism and subsequent chemical oxidation, and protein is bound in an unavailable form (sugar-protein polymer) through browning or the Maillard reaction.

Mold growth on hay and the resulting dustiness have created problems with human and animal health. Farmer's lung disease, a form of pneumonia, is associated with inhalation of dust containing the spores and dried mycelia of fungi by persons handling molded hay. Moldy and dusty forage is less palatable to animals. In addition, livestock illness can occur as a result of mycotoxins produced by microbes in moldy hay.

Hay Preservatives

In the past, farmers salted moist hay as it was placed in storage. The purpose was to preserve hay and improve its palatability. However, salt is ineffective as a preservative unless applied in amounts physiologically harmful to animals. Benefits observed due to salt addition probably resulted from an increased palatability of treated hay and fire retardant properties.

Compounds that liberate carbon dioxide were marketed on the premise that molds cannot live in pure carbon dioxide. Sodium and calcium bicarbonate were the main ingredients. Research has indicated that it is impossible to produce enough carbon dioxide in this way to exclude all the oxygen from a haymow. Other unfeasible "preservatives" include drying agents such as calcium chloride ($CaCl_2$) and silica gel, and chlorinated phenols. These have been rejected for economic and safety reasons.

Organic acids and their salts have been used successfully to preserve grain and silage and are being marketed as hay preservatives. The effective ingredient in most commercially available preservatives is propionic acid. It is mixed with acetic acid, inorganic acids, formaldehyde, water or flavoring ingredients.

Organic acids function as fungicides and must be applied to hay to contact as much of the surface as possible. Formaldehyde has bactericidal as well as fungicidal properties. Organic acids have a residual effect, providing long-term protection if not diluted by wetting and moisture migration. If hay bales and stacks are open, volatilization of organic preservatives will occur and their effectiveness will decrease. Rain will dilute and leach organic acids applied to hay; therefore, treated hay should be covered.

Anhydrous ammonia injected into hay reacts with moisture, condenses, and prevents mold growth. Forage crude protein levels increase due to the nitrogen content of the gas, and digestibility increases as a result of delignification of the forage.

Experimental Results with Preservatives

Research at several universities has shown that organic acids can prevent excessive heating, mold formation and dry matter loss of moist hay (25 to 35 percent moisture) during storage. Purdue University research (Table 1) demonstrated that propionic acid applied at 1 percent by weight (20 lb. per ton) to hay containing 32 percent water effectively prevented heating. Hay treated with propionic acid at rates of 0, .02, 0.2 and 0.5 percent reached temperatures above 104° F within a few days after baling while the temperature of hay treated with a 1 percent rate was similar to air temperature.

Some loss of dry matter and digestibility occurred in all treatments, but these losses were lowest at the 1 percent rate, which indicates that microbial activity was reduced. The control and low level acid-treated hays (.02, 0.2 and 0.5 percent) were visibly moldy and deteriorated. The hay treated at the 1 percent rate lost green color, but otherwise appeared in good condition. Effectively treated hay lost moisture slower than untreated hay, which heated. When propionic acid was applied at 0.02 percent (equivalent to 0.4 lb. per ton or 4 lb. of a preservative containing 10 percent propionic acid) the highest temperature and dry matter loss occurred. Unfortunately, this rate and the 0.2 percent rate have been recommended for some commercial products.

Table 1. Storage losses and composition of alfalfa hay baled at 32% moisture and treated with different rates of propionic acid at baling.[1]

Treatment	Max. storage temp.	Dry weight loss	In vitro dry matter digestibility (IVDDM)	Total carbohydrates
	°F	%	%	%
Control	124	15.1	60.5	3.4
Propionic acid				
0.02%	127	16.7	61.8	3.1
0.2 %	115	13.2	62.2	3.9
0.5 %	104	11.7	61.0	4.1
1.0 %	86	7.6	65.0	6.5

[1] Hay at harvest was 70.5% IVDDM.

Source: Knapp, Holt and Lechtenberg, 1976.

Mixtures of propionic acid with acetic acid and with formaldehyde are commercially marketed. A University of Wisconsin report showed that an 80:20 mixture of propionic:acetic acid and a mixture of 1 percent propionic acid plus formaldehyde prevented mold growth and reduced dry matter loss of hays baled at 30 to 35 percent moisture. Untreated hay at the same moisture level molded.

Another Wisconsin experiment compared a 1 percent rate of propionic acid, 1 percent propionic acid plus formaldehyde, and 1 percent methylene-bis-propionate applied to hay baled at 26 to 31 percent moisture and found them to be effective in reducing hay temperature and the resulting heat damaged protein (browning).

The University of Maryland reported no differences between propionic acid and ammonium isobutyrate in preserving alfalfa hay (31 percent moisture) when applied at rates of 0, 1.0, 1.5, 1.75 and 2.0 percent. A rate of 1.5 percent and above of either preservative significantly reduced mold development and maximum temperature and increased forage quality as measured by in vitro digestibility.

In another experiment with hay of 17 to 20 percent moisture, a commercial product containing about 20 percent propionic acid and other ingredients was ineffective in preventing hay heating when applied at 4 lbs. per ton as recommended by the manufacturer.

University of Wisconsin researchers compared dry alfalfa hay with high moisture hay treated with 1 percent propionic acid as feed for lactating dairy cows (Table 2). Daily dry matter intake by cows was significantly higher for field dried hay, but those fed the 1 percent propionic acid treated hay produced slightly more milk. No significant difference in milk fat content was noted between the two hays.

Purdue University researchers treated bales of 32 percent moisture alfalfa hay by injecting anhydrous ammonia or ammonia gas at a rate of 1 percent by weight into a plastic enclosed stack. The ammonia treatment prevented heating, and it increased cell wall digestion and the protein content of the treated hay. Experiments in which a large volume of 50 percent ammonia in air was blown rapidly through loosely packed 36 percent moisture hay indicate treatment also can be achieved in this manner. A five-second exposure to the ammonia-air mixture was enough to preserve the hay for several weeks. A New York dairyman has requested patent rights for an applicator which operates on this principle, but at this printing no commercial method of applying ammonia gas to moist hay during baling is available.

Table 2. Daily dry matter intake and milk production of cows fed alfalfa hay that was field cured or treated with propionic acid (PA).

Parameter	Wet hay[1] treated 1% PA	Dry hay[2] no acid
Dry matter intake:		
Hay, lb.	31.9	33.0
Grain, lb.	7.5	7.5
Total, lb.	39.4	40.5
Production:		
Milk, lb.	48.3	47.1
4% FCM, lb.	48.1	47.6
Fat, %	4.0	4.1
Feed/4% FCM, lb.	1.8	1.9
Weight change, lb/day	1.5	0.8

[1]69.8 and 85.9% dry matter at baling and feeding, respectively.
[2]82.8 and 89.9% dry matter at baling and feeding, respectively.
Source: Adapted from Jorgensen, et al. 1978.

Recommendations on Hay Preservatives

Research indicates that organic acids applied uniformly over the surface of hay at appropriate rates are effective in preserving hay baled up to 35 percent moisture (Table 3). Rates of application are on a dry matter basis and are appropriate for propionic acid, 80:20 percent propionic:acetic acid mixes, 70:30 percent propionic acid:aqueous formaldehyde, and ammonium isobutyrate. Although preservatives are effective in preventing hay deterioration at moisture levels greater than 35 percent, the practice is not recommended because of the preservative cost and the difficulty of handling wet bales. Moisture levels can be determined by electronic testers or by other methods. (See AG-FS-0902, "Determining the Moisture Content of Forages".)

Table 3. Recommended rates for applying organic preservatives to hay.

Hay moisture level	Rate dry wt. basis	lb/ton
%	%	
20 - 25	0.5	10
25 - 30	1.0	20
30 - 35	1.5	30

For best results, preservatives should be applied at the baler. Applying organic acids during raking or conditioning is not recommended since volatility may reduce effectiveness and because preservatives have herbicidal activity.

The preservative should be applied to achieve maximum coverage of the plant material. To make this easier, spray nozzles are placed at the pick-up reel of balers and choppers (Figure 2). The basic equipment consists of a storage container for the preservative, a 12-volt pump powered by the electrical system of the tractor, spray nozzles, flow meter and plastic tubing. Mixing the preservative with water (1:1) permits more thorough coverage of the plant material without decreasing effectiveness. However, if water is added, the rate of diluted preservative must be increased to apply the same amount of active ingredients.

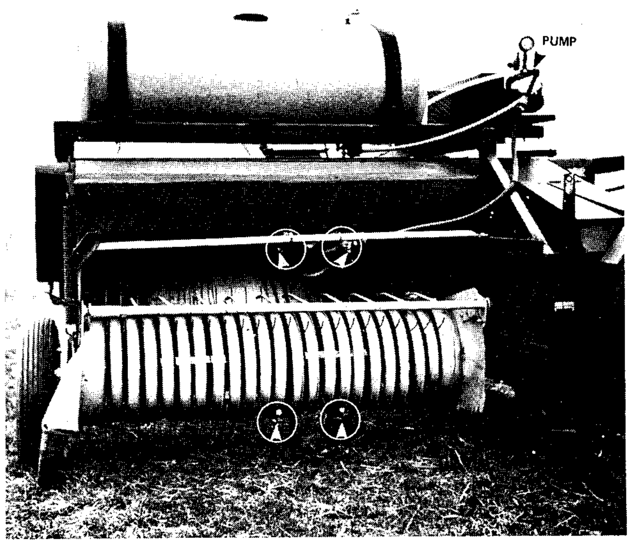

Figure 2. A conventional baler modified with a 400-gallon tank, corrosion resistant, variable speed pump, and four nozzles (indicated by arrows).

To apply the amounts of preservatives shown in Table 3, some information must be calculated. The forage handling capacity of the harvesting equipment in tons per hour must be determined and the pressure regulator or nozzle tips of the applicator system adjusted to spray a predetermined amount or weight of preservative per hour.

Pounds of organic preservative can be estimated using the following formula:

$$\frac{\text{lb. of preservative}}{\text{ton hay}} =$$

$$\text{tons hay baled/hr}^1 \times \text{gal. solution}^2 \times 8.3^3 \times \frac{\text{\% organic acid}^4}{100}$$

[1]Capacity of baling equipment in ton/hr.

[2]Gallons of solution sprayed by equipment with a given pressure and nozzle tip.

[3]Assumes 1 gallon of preservative solution weighs 8.3 lb.

[4]Percent propionic acid or propionic acid and formaldehyde mixture in the preservative.

Do Hay Preservatives Pay?

Harvesting hay at higher moisture levels than normal decreases leaf loss and the chance of rain damage. Recommended hay preservatives applied to high moisture hay reduce microorganism growth, subsequent spontaneous heating and dry matter loss while maintaining forage quality. But the question remains as to whether hay preservatives are worth the cost.

Table 4 shows several situations that a farmer could face: a) hay is baled at less than 25 percent moisture; b) hay is rained on prior to complete drying; c) hay is baled wet (32 percent moisture) to avoid rain damage; d) hay is baled wet using a preservative. At higher moisture levels, harvest losses decrease but storage losses increase. Storage losses for preserved hay would probably have been lower if the recommended rate of acid had been used. When the situations are compared based on TDN yield/acre, the use of preservatives is economically superior to rained-on hay but not field drying without rain. If propionic acid costs $.40 per pound, the treatment of hay would cost $8 per ton. With hay priced at the TDN value of $2.50 per bushel of corn, the preservative treatment appears to more than pay for itself when compared with the rain-damaged or untreated wet hay alternatives.

Table 4. A comparison of four hay harvesting situations.

	Baled dry[1]		Baled wet	
	no rain	1" rain	untreated	1% PA
Yield before cut, lb/A	2,000	2,000	2,000	2,000
TDN before cut, %	70	70	70	70
Respiration loss in field, %[2]	5	10	5	5
Harvest loss, %[2]	10	15	5	5
Harvested yield, lbs/A	1,700	1,500	1,800	1,800
Storage loss, %[2]	5	5	18	10
Final yield, lb/A	1,600	1,400	1,440	1,600
Final TDN, %	66	61	59	64
Final TDN yield, lb/A	1,056	854	850	1,024
% TDN lost after cut	25	39	39	27
Value/A[3]	58.08	46.97	46.75	56.32

[1]Baled dry at 25% moisture; baled wet at 32% moisture.
[2]Percent dry matter lost.
[3]TDN valued at $.055/lb (shelled corn at $2.50/bu).
Source: Adapted from Holt and Lectenberg, 1976.

Problems with the Use of Organic Acids as Hay Preservatives

Organic acids are corrosive and should be handled with care. Read labels on containers. Goggles and protective clothing should be used when transferring preservatives. Water should be available at all times, including in the field, to flush skin and eyes in case of accident. Baking soda is an effective neutralizing agent. Equipment surfaces and tanks that come in contact with the preservatives should be washed after use, and the spray system should be flushed. Stainless steel pumps, fittings and nozzles are necessary to reduce corrosion.

Hay baled at high moisture levels should not be mixed with field-cured hay that has a low moisture content. Moisture may migrate to dry areas if heating occurs. Dry hay that comes in contact with moist hay will absorb moisture, and mold growth may occur.

Summary

- Harvesting hay at moisture levels greater than 25 percent reduces field losses by decreasing leaf shattering, which occurs in hay making operations, and by decreasing time of exposure to adverse weather conditions.
- Storage of hay at moisture levels greater than 25 percent without a hay preservative usually results in mold growth and a subsequent temperature rise. Forage quantity and quality are decreased and in some conditions spontaneous combustion can occur.
- Hay preservatives reduce storage losses of hay baled at a moisture content of 25 to 35 percent. Compounds containing greater than 60 percent propionic acid are currently the most reliable for hay preservation.
- Recommended organic acid application rates increase as hay moisture levels increase; thus rates need to be adjusted during baling.
- Hay preservatives must be carefully evaluated from an economic viewpoint and in relation to individual farm operations.

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