CHAPTER TWELVE

HAY CURING, BALING, AND STORAGE

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Significant yield and quality losses occur when alfalfa is not harvested correctly. The goals of harvesting are to cut alfalfa at the growth stage that provides the optimum combination of yield and quality and to maintain quality and minimize losses through rapid curing and timely raking and baling. There is increasing interest in maximizing hay quality through variety selection and management. These efforts are nullified if the high-quality alfalfa is not harvested and stored properly.

Nearly all alfalfa in the Intermountain Region is harvested for hay, so this chapter emphasizes hay-making practices rather than those used when making green chop or silage. The hay-making procedure most commonly used in the Intermountain Region is a four-step process. It begins with cutting the alfalfa, which is usually done with a 12- or 14-foot self-propelled swather. After a few days the partially dried, or cured, hay is raked to turn the windrow, and two windrows are combined or laid side by side. This hastens the curing process and improves the efficiency of the baling operation. After the hay has dried sufficiently, it is baled. Finally, it is roadsided by a self-propelled bale wagon.

HAY CURING

One of the most critical aspects of harvesting is drying cut alfalfa to a point where it can be safely baled. This is especially true in the Intermountain Region, where thunderstorms pose a significant and continual threat. Rapid, uniform curing of alfalfa is highly desired. It minimizes quality losses due to bleaching, respiration, leaf loss, and rain damage and improves subsequent yields by reducing the effect of windrow shading, lessening traffic damage to regrowth buds, and allowing timely irrigation after cutting.

The moisture content of alfalfa growing in the field is generally between 75 and 80 percent. The drying rate of cut alfalfa depends upon several environmental variables. These include solar radiation, temperature, relative humidity, soil moisture, and wind velocity. Research in Michigan and California indicates that solar radiation is by far the most significant environmental factor influencing drying rate.

The objective of the hay producer is to utilize management practices that accelerate the drying rate within the confines of uncontrollable environmental conditions. To determine which management practices would be most effective, it is helpful to understand the alfalfa drying process.

The drying process of alfalfa occurs in two phases. The drying rate during each phase is governed by the resistance to water loss from the plant (Figure 12.1 explains various resistances to moisture loss). The first phase, or rapid drying phase, accounts for approximately 75 percent of the moisture loss that occurs during the curing process and requires only 20 percent of the total drying time. The stomata (leaf pores) are wide open, and moisture loss occurs from leaves through these openings and from water transfer from the stems through the leaves. Some water also departs through the cut ends of stems and through bruised tissue. The main limiting factor to drying during the first phase is boundary layer resistance, the resistance offered by the layer of still moist air around the plant. Wind moving over and through the windrow can accelerate drying by replacing the moist air in the boundary layer with drier air. The first phase is usually complete before the end of the first day after cutting. The second phase, the slow drying phase, commences at about 40 percent moisture content, when the pores of the leaf and stem close. Stomatal resistance increases immensely and drying rate depends on cuticular resistance. Compared to moisture loss in the initial phase, moisture loss is extremely slow in this phase. In fact, the drying rate in this phase is 1⁄100 the initial drying rate.

Figure 12.1 Resistances to water loss from alfalfa.

- Boundary layer resistance: resistance related to the layer of still moist air close to the plant surface
- Cuticular resistance: the resistance of the plant surface to water movement
- Stomatal resistance: resistance that is controlled by the pores on the surfaces of leaves and stems

Wide windrows often dry one day faster than narrow windrows . . . more of the alfalfa is exposed to radiant solar energy.

Mechanical Conditioning

To accelerate curing, many growers mechanically condition or crimp the alfalfa as they cut it. In fact, mechanical conditioning has become a widely accepted practice. Most conditioners lightly crush the forage between intermeshing rollers located behind the header of the swather. The primary rationale for crimping is to crush and break the stems, which dry more slowly than leaves, thus facilitating water loss and bringing the drying rate of stems more in line with that of leaves. Mechanical conditioning affects both phases of the drying process. It accelerates the rapid phase by crushing stems, and it accelerates the slower phase by breaking the cuticle. Sometimes growers question the effectiveness of mechanical conditioning and wonder if the cutting operation could be simplified if the conditioning rollers were removed. Research has shown that mechanical conditioning hastens the drying process by as much as 30 percent. Drying time saved by mechanical conditioning can vary considerably, however, depending on weather conditions and alfalfa yield. Conditioners should be set so that stems are cracked and crushed but not cut or severely macerated. Consult the owner's manual for proper conditioner adjustment.

Chemical Conditioning

Chemical conditioning involves the use of a drying agent, usually potassium carbonate or a mixture of potassium and sodium carbonate. A drying agent is applied during swathing. The chemical hastens the drying process by allowing water to pass more freely through the waxy cuticle on the plant surface. Thus, drying agents affect the second, or slow, phase of the drying process. These agents are most effective when the weather is warm and sunny. Under poor curing conditions or when there is rain during drying, drying agents present no advantage. Drying agents have not become popular in the Intermountain Region (or in California as a whole) because of their cost, the need to haul large volumes of water to and through the field to apply them, and the good curing conditions in most of California (compared to those in the Midwest). Therefore, they are not believed to be cost-effective in most situations in the Intermountain Region.

Swath Management

Wide, airy windrows dry more rapidly than conventional ones, which are narrow and dense. This has been demonstrated in several California trials and in numerous trials throughout the United States (Figure 12.2). The extent of the advantage that wide windrows offer depends on the geographic area, the time of year, and the yield level. In general, wide windrows are most beneficial in the spring, when yields are high and day length is long (that is, there is more solar radiation than in other seasons). Wide windrows often dry one day faster than narrow windrows because the forage is spread out and more of the alfalfa is exposed to radiant solar energy. Also, because they encounter less boundary layer resistance, wide windrows do not inhibit moisture movement to the degree narrow ones do. Wide windrows improve the uniformity of drying, which affects when alfalfa can be raked and baled. The start of these practices is determined not by the average windrow moisture content, but by the moisture content of the wettest portion of the windrow. Therefore, since the moisture content of wide windrows is relatively uniform, they can be raked and baled earlier. If wide windrows are not raked earlier, their advantage is lost.

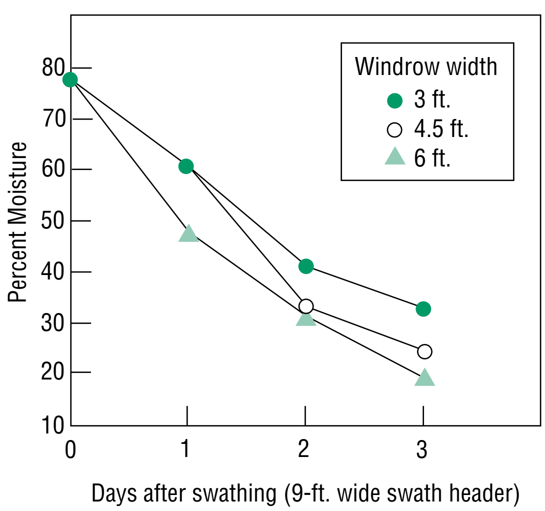


Figure 12.2. The effect of windrow width on alfalfa drying rate. (*Source:* Klamath Agricultural Experiment Station, Oregon State University.)

Some growers are reluctant to switch to wide windrows; they fear that, because wide windrows expose more surface area to the elements, color loss from bleaching will result. However, researchers who have compared alfalfa from wide and narrow windrows have not observed any significant color difference. Although wide windrows do expose more alfalfa, they usually can be raked and baled sooner, so exposure time is reduced. Also, wide windrows remain wide only until they have dried sufficiently to rake. Raking usually occurs after the first drying phase. Little bleaching occurs during the initial phase, because the waxy cuticle of the plant is largely intact. During the final curing phase, when most bleaching occurs, wide windrows have been raked and combined so they are no wider than raked conventional windrows.

Many growers have not switched to wide windrows because of equipment limitations; the width of conditioning rollers and windrow baffles determines windrow width. Some new swather designs have conditioners nearly as wide as the swather header, so growers can alter windrow width with a simple adjustment of a lever. Fortunately, inexpensive windrow conditioner shields have been developed that modify traditional swathers so they can spread windrows.

Because of their width, wide windrows must be raked prior to baling and cannot be baled directly out of the swath. Obviously, this is not a problem in areas where windrows are always raked. Also, windrow width should not be greater than that which can be easily managed with available rakes.

Raking

The purpose of raking is to expedite the drying process by transferring the alfalfa to drier soil and inverting the windrow. Inversion exposes alfalfa on the bottom of the windrow, which at this point has a higher moisture content than that at the top. Also, raking usually combines two windrows, thus facilitating baling and roadsiding. Raking is very effective, but it must be done at the proper moisture content; otherwise, excessive yield and quality losses will occur (Figure 12.3). Many growers rake alfalfa when it is too dry.

The optimum moisture content for raking is 35 to 40 percent. At this moisture content, a significant increase in drying rate is achieved while severe leaf loss is avoided. Raking at too high a moisture content may twist (commonly referred to as rope) rather than invert the hay and can actually slow drying rate. Leaf loss associated with raking hay too dry is significant. When raking hay at 20 percent moisture content, 21 percent of leaves are lost; when raking at 50 percent moisture, only 5 percent are lost (Table 12.1). Therefore, hay raked just prior to baling will be too dry. The greatest loss is in the leaf fraction. Such loss significantly reduces the quality of the hay, since leaves are its most nutritious component. Research has shown that raking alfalfa hay that is too dry is more detrimental to hay quality than baling when too dry. In one study, late raking resulted in a 25 percent loss in yield and a 2- to 4-percentage unit reduction in total digestible nutrients (TDN). (Baling when too dry resulted in a 5-percent loss.) If alfalfa was both raked and baled too dry, the loss increased 10 percent over the raking loss.

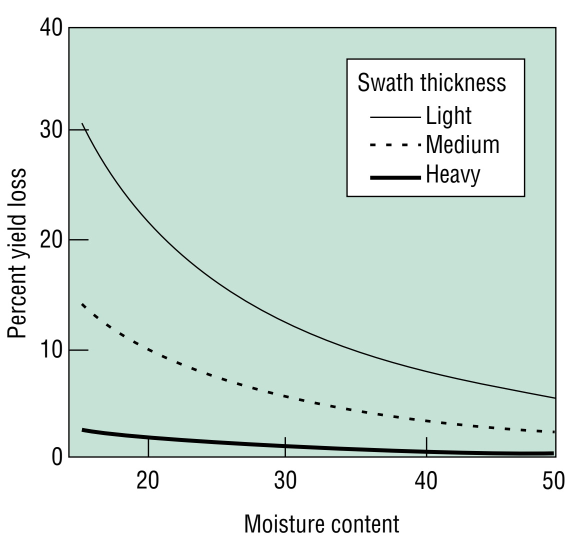


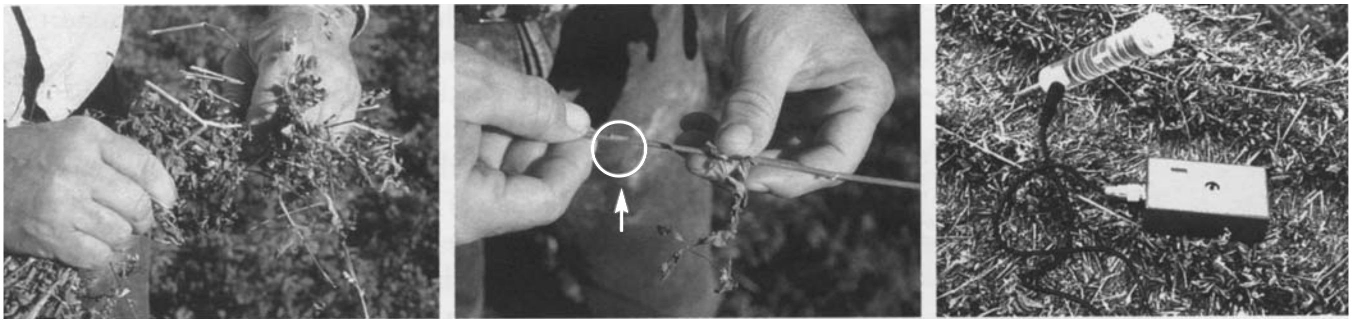
Figure 12.3. The effect of moisture content and swath thickness on dry-matter losses during raking. (*Source:* C. A. Rotz, Michigan State University.)

BALING AND STORAGE

Alfalfa must be baled within a relatively narrow range of moisture content to avoid losses in yield and quality. Whenever possible, refrain from baling hay that is below 12 percent moisture, because leaf shatter and loss will be excessive. Hay baled at too high a moisture content is subject to problems with mold and discoloration. The maximum moisture content for baling depends on bale size and density. In general, bale small two-tie bales at less than 20 percent moisture, larger and denser three-tie bales at less than 17 percent, and 1-ton bales at less than 14 percent. The source of moisture within the bale affects the upper moisture limit for safe baling. Hay can be baled at a higher moisture content when the moisture source is free moisture (dew) than when it is moisture trapped inside the stem (stem moisture). Free moisture is more readily dissipated than stem moisture.

Moisture Content Estimates

A simple and practical method to determine if alfalfa hay can be safely baled is to grab a handful of alfalfa with both hands and twist it by rotating your wrists in opposite directions. If the stems crack and break, the hay is usually dry enough to bale. The thumbnail test is an even better method. Scrape an alfalfa stem with your thumbnail. If the epidermis, or outside layer, cannot be peeled back, the hay has dried sufficiently (Figure 12.4). A moisture meter is a valuable tool to evaluate the moisture content of hay. Resistance-type moisture meters are used as hand probes or mounted on the baler chamber for on-the-go moisture monitoring. How dependable are readings from moisture meters? Researchers have tested their accuracy and found that their readings were within 2.6 percentage points of actual moisture content. Generally, meters indicate a moisture content that is slightly higher than



(A) (B) (C)

Figure 12.4. Three methods to evaluate the moisture content of alfalfa hay. (A) The twist method: Grab a handful of alfalfa with both hands and twist it by rotating your wrists in opposite directions. If the stems crack and break, the hay is dry enough to bale. (B) The thumbnail test: Scrape an alfalfa stem with your thumbnail. If the epidermis, or outside layer, cannot be peeled back, the hay has dried sufficiently. (C) Resistance moisture meters: Probe the bale several times and read the meter to learn the moisture content.

the actual content. They measure stem moisture less accurately than they measure dew moisture.

Moisture for Baling

After alfalfa is fully cured, dew or high relative humidity must soften the leaves. Otherwise, excessive leaf loss will occur during baling. Sometimes, mostly in midsummer, dew or humidity is insufficient for this purpose. Delaying the baling operation to wait for dew is undesirable—yield declines and leaf loss increases the longer hay is left in the windrow. The chance of rain damage also increases proportionately. Additionally, waiting for dew postpones other necessary operations (such as irrigation and cutting of other fields), thus disrupting the cutting cycle and possibly reducing yield and quality.

Windrows can be sprayed with water to compensate for a lack of dew or on days when humidity is insufficient to permit baling. A three-tier boom setup with seven hollow cone nozzles is an effective spray system (Figure 12.5). Two adjustable hollow cone nozzles are mounted on each of the two leading booms. The spray angle of these adjustable nozzles is narrowed to promote water penetration into the windrow. Three standard hollow cone nozzles are mounted on the trailing boom to mist over the entire windrow. Water is sprayed on the windrow at the rate of 40 to 50 gallons per acre. Depending on weather conditions, allow 10 to 30 minutes between water application and baling; this time allows the water to penetrate and soften the leaves. This practice is often an acceptable substitute for natural dew, or it can be used to extend the baling period on days with marginal humidity. However, applying water to windrows does not make midday baling possible. The high evaporation rate at this time negates the effectiveness of spraying.

Table 12.1 Yield and leaf loss during harvest operations.

OPERATION	YIELD LOSS[1] (%)	LEAF LOSS (%)
Mowing and conditioning	2	3
Raking		
At 60% moisture	2	3
At 50% moisture	3	5
At 33% moisture	7	12
At 20% moisture	12	21
Baling, pickup and chamber		
At 25% moisture	3	4
At 20% moisture	6	4
At 12% moisture	6	8

Source: Pitt, R. E. 1990. Silage and hay preservation. Ithaca, NY.
1. Reported on a 100% dry-matter basis.

Moisture Content for Safe Storage

The maximum moisture content for safe hay storage is influenced by the uniformity of moisture within bales, climatic conditions during storage, and ventilation at the storage site. The moisture content of high-moisture bales can be reduced somewhat by allowing them to remain in the field until late afternoon; then road-

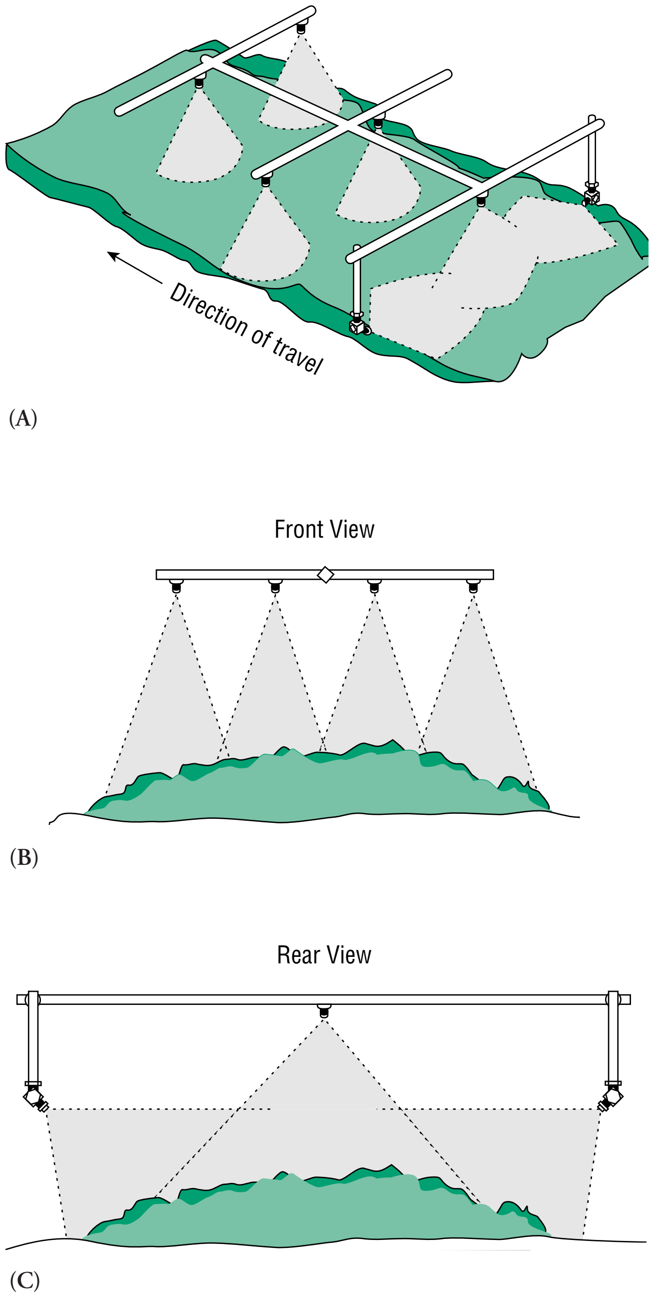


Figure 12.5. (A) This figure shows a three-tier spray boom configuration for adding moisture to windrows. Two adjustable hollow cone nozzles are mounted on each of the two leading booms. Only two nozzles are mounted on each boom so that the sprays do not intersect and deposit an excessive amount of water where the patterns overlap. Three standard hollow cone nozzles are mounted on the third boom. (B) As the front-view illustration shows, the boom setup contains a total of four adjustable hollow cone nozzles. Their spray angle is narrowed to promote water penetration into the windrow. (C) The three standard hollow cone nozzles on the trailing boom mist over the entire windrow. As the rear-view illustration shows, the two outer nozzles are mounted on drops, with swivels. The swivels are angled in, toward the windrow.

side them. Another way to reduce moisture content is to position balewagon loads outside with a gap between the stacks before storing the bales in a barn. Unfortunately, these methods are only partially effective; neither method can dissipate moisture deep within the interior of bales.

Significant yield and quality losses can occur during storage. Studies have indicated dry-matter losses of 1 percentage point for each percentage of moisture above 10 percent. Quality losses can take several forms. Molds may develop in hay stored at a moisture content greater than 20 percent. Molds can produce toxins that reduce palatability and are hazardous to livestock. Mold respiration causes heating, and, when hay temperatures exceed 100ºF (38ºC), browning reactions begin. Reactions that occur during browning, coupled with heating from mold growth, can cause temperatures to increase further. Heating may reduce the protein and energy available to the animal that consumes the hay (Table 12.2). When bale temperatures exceed 150ºF (66ºC), spontaneous combustion can occur. This is most likely in hay with a moisture content over 30 percent.

Heating during the first month actually helps dry hay; hence, after the first month, hay has usually dried to a moisture content where it is stable and can be stored safely. Therefore, any problems that result from storing hay with an excessive moisture content are most likely to occur during the first month of storage. Although the majority of dry-matter losses during storage occur in the first month, Rotz (1994) and others

Table 12.2. Problems associated with hay heating.

TEMPERATURE	PROBLEM
115º–125ºF (46º–52ºC)	When coupled with high moisture, molds and odors develop and decrease palatability.
> 120ºF (49ºC)	Heating reduces digestibility of protein, fiber, and carbohydrate compounds.
130º–140ºF (54º–60ºC)	Hay is brown and very palatable because of the carmelization of sugars; unfortunately, nutritional value is reduced.
>150ºF (66ºC)	Hay may turn black and spontaneous combustion is possible.

Source: V. L. Marble

When bale temperatures exceed 150°F, spontaneous combustion can occur. This is most likely in hay with a moisture content over 30 percent.

found that losses continue at a rate of about 0.5 percent per month for the remainder of the storage period.

Bale Ventilators

A bale ventilator creates a hole through the center of a standard rectangular two- or three-tie bale. The hole is formed by a spear, 8 to 10 inches long, that is mounted on the center of the baler plunger face. The spear produces a 2-inch-diameter hole through the entire bale as the hay is compressed in the chamber. Theoretically, the hole facilitates the dissipation of moisture from the bale, preventing spoilage of high-moisture hay (hay with a moisture content up to 25 percent). However, tests conducted at Michigan State University showed no benefit from using a bale ventilator. The bale ventilator did not reduce hay temperature, dry-matter loss, or moldiness, nor did it improve hay quality or color.

Preservatives

Preservatives are intended to allow storage of alfalfa hay baled at moisture contents higher than would ordinarily be considered safe. They are used on hay baled between 20 and 30 percent moisture. The advantages of baling at higher moisture contents are reduced leaf loss and reduced field curing time, which may help avoid rain damage.

Hay preservatives are usually applied at baling. Organic acids, primarily propionic acid or propionic-acetic acid blends, are the most common preservatives. They prevent mold growth and heating losses by lowering alfalfa pH and retarding the growth of microorganisms that cause hay spoilage. One disadvantage of preservative use is cost. The required application rate for propionic acid is 10 pounds per ton for hay with a moisture content of 24 percent or less. For hay with a moisture content from 25 to 30 percent, the rate is 20 to 25 pounds per ton. These application rates lead to relatively high expenses. What is more, preservatives are seldom 100 percent effective. The causes of erratic effectiveness are uneven application and areas of high moisture content within a bale. (An area of a bale with high moisture content is commonly called a slug.) In addition, propionic acid is hazardous to skin and eyes and corrosive to farm equipment. Alternatives to propionic acid include microbial inoculants and enzymatic products, but their results have been unsatisfactory in most university-sponsored tests. Most researchers conclude that using a preservative to reduce leaf loss is not usually cost-effective. Preservative use may be justified only if the product can be used selectively, when rain is imminent. But, as everyone knows, predicting rain can be very difficult.

ADDITIONAL READING

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