

# Harvesting, Curing, and Preservation of Alfalfa

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**Chapter 14**

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Significant yield and quality losses result when alfalfa is not properly cured, preserved, and stored. Growers invest considerable time, inputs and money into producing a high yielding, high quality alfalfa crop. 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 proper preservation. All of the efforts that go into producing high-quality alfalfa can be nullified if the crop is not harvested and stored properly.

## Harvesting and Processing Strategies

Alfalfa offers tremendous flexibility in providing feed for animal consumption. The majority of the alfalfa produced in the western United States is harvested and baled as hay. However, growers may opt to cut and feed the alfalfa directly to dairy cows (greenchop), or ensile the alfalfa in large plastic bags, covered piles, or pits. Packaging alfalfa into cubes and pellets has also been practiced but is not common today.

The main difference between the alfalfa products is moisture content. Moisture content is the critical aspect of success for hay and ensilage success (Fig. 14.1). Greenchop has the highest moisture content, followed by silage, and lastly hay and cubes. Each harvest strategy has advantages and disadvantages, since each harvest and storage option has potential risks of dry matter and quality losses (Table 14.1). The alfalfa preservation strategy of choice depends on several factors: whether the alfalfa is sold or fed on-farm, distance to market, weather conditions, equipment available, and market demand for different alfalfa products. A description of the different alfalfa products and methods involved in their production is provided in this chapter.

## Greenchop Alfalfa

Greenchopping is a harvest technique that involves cutting and chopping alfalfa into a feed wagon. The fresh forage is then delivered directly to the animals. Greenchopping alfalfa is common practice for the first cutting in the spring and late cuttings in the fall when making hay is risky due to weather conditions, and when fields are in close proximity to animals. However, there are operators that greenchop some of their alfalfa throughout the year.

### Advantages

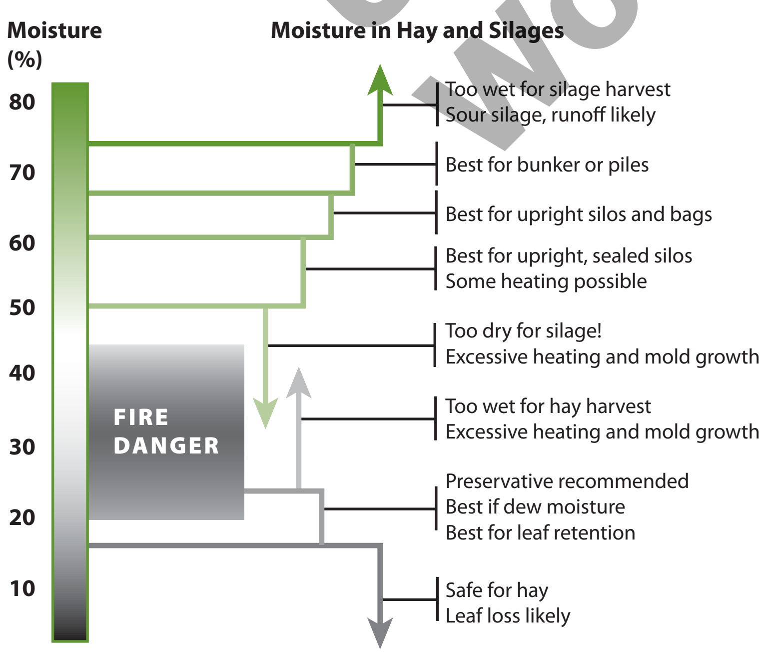
If all cuttings in a growing season are greenchopped for direct feeding or silage, an overall yield increase of 10–12 percent is expected. Several factors contribute to the yield increase. Handling the forage when it has a high moisture content avoids leaf loss that occurs when raking or baling for hay production. This also contributes to higher quality. Traffic in the field from tractors and equipment used in raking, baling, hauling, and stacking is reduced in a greenchop system because the forage is harvested and removed in a single pass.

There are two distinct advantages to reducing traffic in the field, which lead to improved yield and stand longevity. Greenchop methods avoid heavy traffic, which can result in soil compaction problems that limit production. Traffic also damages the crowns and injures newly emerging shoots. This may contribute to disease problems and delayed regrowth. Traffic has a much greater effect on regrowing stems several days after harvest (during raking and baling), and a negligible effect during cutting. Removing the forage from the field immediately or soon after cutting has many advantages. Irrigation can follow shortly after harvest, resulting in less stress to the alfalfa. Reducing traffic damage and preventing stress from delayed irrigation allow for the crop to come back more quickly following harvest, often allowing for an additional cutting each growing season.

The ability of greenchop systems to avoid quality damage due to rainy weather is also an important advantage, compared to making hay. This is especially true in the spring and fall, when field drying times are much longer and weather more unpredictable in Mediterranean climates.

**FIGURE 14.1**

Moisture ranges for proper preservation of alfalfa as silage or hay.




Adapted from Pioneer Forage Manual, 1990

### Disadvantages

Greenchopping is only practical when the field and the animals to be fed are in close proximity. Greenchop is a high-moisture feed (75–80% water), and hauling that amount of water long distances is not economical. A disadvantage to greenchop from the dairy perspective is the day-to-day variability of the feed. The forage must be fed quickly, so the grower only cuts as much feed as can be used that day. The alfalfa remaining in the field declines in quality as plants continue to mature. Variability is even greater if more than one field is being greenchopped to supply the fresh forage. Another disadvantage is that equipment must be taken to the field on a daily basis to harvest a supply of forage.

Exercise caution when greenchop is first fed, or when it is fed at the end of the season when moisture content is higher, because bloat can be a factor. The potential for bloat also exists if the alfalfa is very immature when greenchopped. Additionally, greenchop systems can cause excessive looseness in the stool when fed at high rates. In some cases, nutritionists would recommend feeding dry feeds in combination with greenchop, or feeding greenchop incorporated with a total mixed ration (TMR).

## Alfalfa Silage (Haylage)

Alfalfa can be stored for a long period by ensiling it. Silage is a preserved feed that retains its nutrient value when handled properly. Table 14.2 lists proper silage-making processes that prevent losses and retain quality. To make alfalfa silage (haylage), the alfalfa is cut and left in the field to wilt until it reaches 60–70 percent moisture content. Depending on the weather, the alfalfa may remain in the windrow from a half day to a full day to reach the desired moisture content. Uniformity in

**TABLE 14.1**

Estimation of typical dry matter (DM) yield losses and quality changes during the major processes used in alfalfa harvest and storage (adapted from Rotz and Muck, 1994; Rotz, 2005)

| Process | Loss in Yield (DM) Range (%) | Loss in Yield (DM) Average (%) | Change in Forage Quality (DM basis) CP (%) | NDF (%) | DDM* (%) |
|---|---|---|---|---|---|
| **Post-Harvest Field Losses** | | | | | |
| Respiration losses** | -1 to -7 | -4 | +0.9 | +1.7 | -1.7 |
| Rain damage**, 0.2 inch | -3 to -7 | -5 | - 0.4 | +1.4 | -1.5 |
| 1.0 inch | -7 to -27 | -17 | -1.7 | +6.0 | -7.0 |
| 2.0 inch | -12 to -50 | -30 | -3.5 | +14.0 | -14.0 |
| **Harvest Effects** | | | | | |
| Mowing/conditioning | -1 to -4 | -2 | - 0.7 | +1.2 | -1.4 |
| Tedding | -2 to -8 | -3 | - 0.5 | +0.9 | -1.2 |
| Swath inversion | -1 to -3 | -1 | 0.0 | 0.0 | 0.0 |
| Raking | -1 to -20 | -5 | - 0.5 | +1.0 | -1.2 |
| Baling, small bale | -2 to -6 | -4 | - 0.9 | +1.5 | -2.0 |
| round bale | -3 to -9 | -6 | -1.7 | +3.0 | -4.0 |
| large rectangular bale | -1 to -4 | -3 | - 0.7 | +1.0 | -1.5 |
| Chopping | -1 to -8 | -3 | 0.0 | 0.0 | 0.0 |
| **Storage Effects** | | | | | |
| Hay storage, covered | -3 to -9 | -5 | - 0.7 | 2.0 | -2.0 |
| outside | -6 to -30 | -15 | 0.0 | 5.0 | -7.0 |
| Silo storage, sealed | -6 to -14 | -8 | 1.4 | 0.7 | -3.7 |
| stave | -7 to -17 | -10 | 1.8 | 1.7 | -4.7 |
| bunker | -10 to -16 | -12 | 2.3 | 2.7 | -5.6 |

* Decrease in digestible dry matter or total digestible nutrients (TDN). This also reflects the loss of energy available to the animal.

** Respiration loss includes plant and microbial respiration for crops cured without rain damage. Rain damage includes leaf loss, nutrient leaching, and respiration resulting from rewetting.

moisture content is important. Moisture should be tested throughout the harvest to keep it within the desired range. If too much moisture remains in the forage at the time of ensiling, nutrients are leached from the pile or pit and run off. Fermentation may also be negatively affected. On the other hand, if the forage is too dry (< 50% moisture content), it is difficult to pack tightly in the pile, pit, or bag. As a result, proper preservation may not be achieved. Heat damage or mold formation may result when forage is too dry. Quality and digestibility are both reduced by browning reactions associated with heating.

Once the alfalfa has reached the target moisture content, windrows are raked together. A forage harvester chops the forage from the windrow and blows it into a silage truck. Alfalfa should be chopped to a theoretical length of cut (TLC) from 0.75 to 1 inch (1.9 to 2.5 cm). If the chop is longer than this, the forage is difficult to pack tightly, especially if it is on the dry side of the recommended range. If the chop is too short, feeding the forage may lead to metabolic problems in the animals consuming the haylage. Silage trucks transport the chopped forage to its final destination and dump it into a pile or pit, or pack it into a bag. Upright silos are rarely used for haylage in this area. Working quickly to tightly pack the forage and covering it to eliminate and exclude oxygen are critically important to the silage-making process. A polyethylene sheet or tarp is placed over the pile and weighted down with discarded tires or other weights. If silage is left uncovered, losses of 51 percent in the top 4 feet can be expected; overall losses of 32 percent or more have been recorded. Inspect covers or bags routinely for punctures or tears. Preventing oxygen from leaking into the system can greatly reduce storage losses.

## The Fermentation Process

The main objective in silage preservation is to exclude oxygen as quickly as possible from the silage mass and reduce pH rapidly through bacterial fermentation. There are four phases to the fermentation process (Fig. 14.2): aerobic, lag, fermentation, and stable.

In the *aerobic* phase, plant respiration and aerobic microorganisms consume oxygen trapped in air spaces in the silage mass. Once oxygen is depleted, the system becomes anaerobic. The transition from an aerobic to an anaerobic environment happens quickly, within a few hours under optimum conditions.

**TABLE 14.2**

Proper silage making practices

| Practice | Reason | Benefits |
|---|---|---|
| Minimize drying time. | Reduce respiration. | Reduced nutrient and energy losses.<br>More sugar for fermentation.<br>Lower silage pH. |
| Chop at correct TLC.[1]<br>Fill silo quickly.<br>Enhance compaction.<br>Seal silo carefully. | Minimize exposure to oxygen. | Reduced nutrient and energy losses.<br>More sugar for fermentation.<br>Reduced silo temperatures.<br>Less heat damage (browning).<br>Faster pH decline.<br>More extensive pH decline.<br>Better aerobic stability.<br>Less chance of *listeria*.<br>Less protein solubilization. |
| Ensile at 30%–50% DM content. | Optimize fermentation. | Reduced nutrient and energy losses.<br>Proper silo temperatures.<br>Less heat damage (browning).<br>Control *clostridia*.<br>Prevent effluent flow. |
| Leave silo sealed for at least 14 days. | Allow complete fermentation. | Lower silage pH.<br>More fermentation acids. Better aerobic stability. Less chance of *listeria*. |
| Unload 2–6 in./day.<br>Keep smooth surface. | Stay ahead of spoilage. | Limit aerobic deterioration. |
| Discard deteriorated silage. | Avoid animal health problems. | Prevent toxic poisoning, myocotic infections.<br>Prevent listeriosis, clostridial toxins. |

Source: Pitt (1990).

[1]TLC is theoretical length of cut.

Once the system becomes anaerobic, the *lag* phase begins. During this phase, cell membranes break down and anaerobic bacteria begin to grow and multiply rapidly, using the plant sugars as a substrate.

During the *fermentation* phase, bacteria convert sugars to acetic and lactic acids, resulting in a low pH and high concentration of lactic acid (at least 70%) in the ensiled forage. Lactic acid is the most efficient fermentation acid and will quickly drop the pH of the silage. The faster fermentation is completed, the more nutrients will be retained in the silage. Well-fermented alfalfa silage should have a pH from 4 to 5. At this pH range, the bacteria die out and the silage enters the *stable* phase, where it remains until feeding begins. The anaerobic (oxygen-free) environment also prevents mold and yeast growth. An online Interactive Module to understand silage-making processes is available (Hall and Wilson 2004).

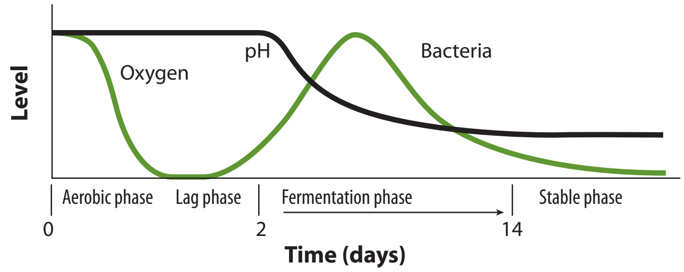
## Inoculating Silage Crops

Alfalfa can be difficult to ensile because of low sugar content and high buffering capacity, as compared to corn or other grasses. Some growers apply silage additives (inoculants) to the forage to aid in the fermentation and preservation process. Most silage additives are designed to improve fermentation by providing bacteria and enzymes. Additives add to the population or enhance the growth of lactic acid bacteria, increasing their production of organic acids that reduce pH. Other types of additives, categorized as inhibitors, slow down various processes in silage preservation and are either aerobic or anaerobic. They include materials like propionates (aerobic inhibitors) or lactic acid (anaerobic inhibitor). Silage additives may improve recovery of silage dry matter by reducing the loss of dry matter during the ensiling process and/or at feeding. Finally, they may improve digestibility, intake, and animal performance.

Composition and application rate should be considered in order to predict the success of an additive. Comparisons between products should be based on the amount of active ingredient supplied per unit (pound) of forage. A common unit is the number of colony-forming

**FIGURE 14.2**

Sequence of phases during the ensiling process. *Source:* Pitt, 1990.




units added per gram of fresh forage (cfu/gram forage). In general, the more cfu's per gram of forage added by an inoculant, the more likely it is to be effective. At a minimum, an additive should provide $10^5$ cfu/g. The intention is that the added microorganisms should dominate the fermentation; produce lactic acid as the sole end product; be able to grow over a wide range of pH, temperature, and moisture conditions; and ferment a wide range of plant sugars. Uniform distribution of the inoculant in the forage is critical for promoting bacterial access to plant sugar. The recommended point of application is during chopping, and liquid materials are preferred over granular.

It is best to wait at least 3–4 weeks to allow for maximum fermentation before the alfalfa haylage is fed. This will result in better aerobic stability. The rate at which the silage is fed must be sufficient to prevent the exposed silage from heating and spoiling. Good management of the feeding face of an open silage pit is critical to prevent spoilage. An average rate of 6 inches silage removal from the face per day is a common recommendation, taking care to remove silage from the entire exposed face. It is important to limit the disturbance of the packed silage to avoid piles of loose haylage. Estimates of storage losses in haylage range from 2 to 12 percent from surface spoilage and fermentation. Losses are often greater in a pile or pit than in bags, where there is less surface exposed at any one time.

## Advantages of Silage

The yield and quality advantages listed earlier for greenchop apply to an alfalfa silage (haylage) system as well. There are more nutrients preserved per acre because of reduced

*The wetter ration is more palatable and digestible, and is preferred by cows, especially during the hot summer months.*

leaf losses, and weather damage is much easier to avoid, compared with haymaking. Although the forage is allowed to wilt in the field, it typically requires only 2–6 hours mid-season, and from 15 to 20 hours during spring and fall, to achieve the proper moisture content for haylage. It is still a high-moisture feed, and traffic is reduced, compared to a haymaking system. There are benefits associated with feeding haylage to cows. The wetter ration is more palatable and digestible, and is preferred by cows, especially during the hot summer months. It is better suited as an ingredient in total mixed rations (TMRs).

## Disadvantages of Silage

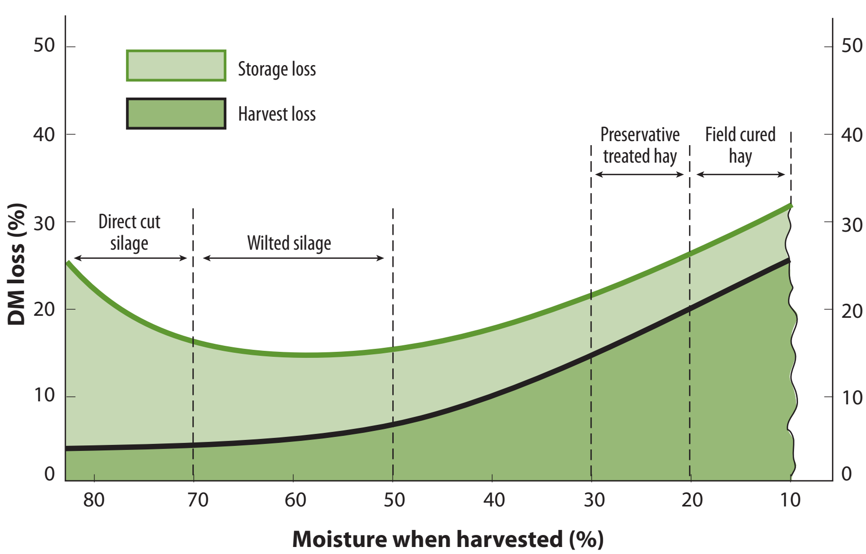
Although field losses are minimal with silage systems, dry matter losses during fermentation can be much higher than in stored hay, often equaling or exceeding the potential field losses observed in haymaking (Fig. 14.3). Additionally there is frequently a loss in digestibility in alfalfa silage compared with fresh or preserved hay (Table 14.1). Since silage is higher in moisture than hay, silage production is limited to those areas in close proximity to the location where the silage will be utilized. Competition for a limited number of custom operators (e.g., baggers) can be an issue. When using bags, a large space to store the product is required because silage bags are typically 10 feet wide and 250 feet long, and they can't be stacked. The bags need to be on a firm surface that allows for access during winter. Bags can be easily punctured or torn, so vigilance is required on the part of dairy personnel to monitor the condition of the bags and make necessary repairs. Once the feed is used, disposal of the plastic bags can be a problem. When haylage is stored in piles or pits, the space requirement is also significant, but not as large as that required for bagged haylage.

When silage is exposed to air, yeast and mold growth cause deterioration resulting from changes in chemical composition, pH, and temperature. Deteriorated forage is usually white due to mold growth, but can be various other colors, depending on mold species. Mold may contain toxins, which are poisonous at certain levels of intake. Aerobic spoilage occurs to some degree in virtually all sealed silos until fermentation is complete and once the silage is disturbed. With poor management, storage and/or losses during feeding can be very high.

A major disadvantage of ensiling alfalfa is protein availability. Through the ensiling process, much of the protein of alfalfa is converted into non-protein nitrogen (NPN). This may be a problem because this protein is made available too rapidly in the rumen, and often is simply excreted as urea. Alfalfa protein from hay is more slowly metabolized by rumen microbes, and thereby is more available to the animal.

**FIGURE 14.3**

Effect of moisture content on silage losses during harvest and storage.



## Determining the Value of Standing Alfalfa for Greenchop or Silage

There are several considerations when estimating the value of alfalfa for greenchop or silage. Both the grower and buyer can gain some advantages by greenchopping alfalfa for either direct feeding or ensiling, as compared to making hay. From the grower's perspective, greenchopping reduces yield and quality losses, as described above. The buyer will gain because protein and total digestible nutrients (TDN) of the haylage will be greater than those of hay. Sorting and refusal in the feed bunk will also be less with haylage than with hay, especially in lower-quality or weedy hay. Some losses do occur in the ensiling process, however. Yield losses (including shrinkage) of 3–7 percent can be expected in bags, and 10–30 percent in a pit-storage system. Such losses would not occur with greenchop.

With any alfalfa forage, price usually depends on factors such as quality, availability, and cost of production. Moisture content is the single largest factor in pricing greenchop or haylage. Because baled hay has significantly lower moisture content than direct-cut alfalfa, the buyer is less concerned with how much is being paid for the "water" in the forage. For

### Calculating the Value of Alfalfa at Different Moisture Levels

Using moisture information, you can adjust the selling price of a typical forage to reflect the difference in moisture content (MC) between two forages. The formula for making this adjustment is:

$$\text{Value of Typical Forage (\$/Ton)} \times \frac{\text{\% DM of Forage to be Priced}}{\text{\% DM of Typical Forage}} = \text{Adjusted Value (\$/Ton)}$$

Dry matter (DM) and moisture content (MC) relate to each other such that,

$$\% \text{ MC} + \% \text{ DM} = 100\%$$

## Determining Forage Moisture Content Using a Microwave Oven

1. Chop fresh forage into 1–2 inch lengths for ease of handling.
2. Weigh out approximately 100 grams (3.5 ounces) of chopped forage.
3. Spread forage thinly on a microwave-safe dish and place in the microwave.
4. Heat for 2 minutes and reweigh.
   a. If forage is not completely dry, reheat for 30 seconds and reweigh. (Microwaves vary considerably in drying capacity. It is better to dry for short intervals and reweigh until the last two weights are constant, than to overdry and run the risk of burning and damage to the oven.) Continue this process until back-to-back weights are the same or charring occurs.
   b. If charring occurs, use the previous weight.
5. Calculate moisture content using the following equation:

   $$\% \text{ moisture content} = \frac{[(W1 - W2) \times 100]}{W1}$$

   W1 = weight of forage before heating
   W2 = weight of forage after heating
6. Dry matter (DM) equals 100% minus % moisture content

   Example: If moisture content = 14%
   DM = 100 – 14 = 86%

To protect the oven, it is recommend that you place a small cup of water in the back of the microwave before beginning this procedure.

greenchop or haylage, however, moisture content varies considerably, and a change of just a few percentage points greatly influences the amount of dry matter (DM) in the load. What is important is the DM being purchased or sold. Always sample the forage as it comes from the field and run a DM analysis. A laboratory analysis will cost about $5–10 per sample, and results are usually available in 24 hours. Dry matter can also be determined on-farm, using a microwave technique (see sidebar). A simple and inexpensive moisture-content measurement ensures that both seller and buyer get a fair price.

When marketing alfalfa for greenchop or silage, the price should be based on the current price for hay in the area (assumed to be at 10–12% moisture) and on actual moisture content of the product. Make purchasing decisions at equivalent moisture contents to accurately determine the price per ton of dry matter. Moisture content should be measured and the product sold on an adjusted DM basis. Harvest costs and labor savings are also important and may be factored into the final price. Although it is often not factored into price negotiations, potential yield increases from greenchopped fields (12%/season) or the fact that a grower is often able to harvest an additional cutting for greenchop when haymaking is not possible, are economic advantages.



### Greenchop Example:

A dairy farmer would like to buy greenchop from a neighboring alfalfa grower. The dairy farmer will harvest the greenchop. Moisture content of the greenchop at the time of harvest and feeding is estimated to be 80 percent (DM = 100% – 80% = 20%). Hay is currently selling for $140 per ton (88% DM). The grower's cost for swathing, raking, baling, and roadsiding the hay is $25 per ton. How much is the greenchop worth per ton at 20 percent DM?

To answer this question, it is first necessary to subtract hay harvesting costs from the current hay price. This must be done to account for the fact that the dairy farmer will be harvesting the greenchop. Therefore the standing crop, greenchop equivalent of the baled hay price is $140 – $25 = $115 per ton, unadjusted for moisture differences. An adjustment for moisture can be made using the previous equation to determine the value of the greenchop at 20 percent DM.

$115/Ton × (20% / 88%) = $26.14/Ton

### Silage Example:

A dairy farmer would like to buy alfalfa for haylage from a nearby grower who will deliver it to him/her. They agreed to price the haylage on the basis of alfalfa hay. The dairy farmer can buy alfalfa hay delivered to the farm for $140 per ton (88% DM). It is expected that the haylage will have about 45 percent dry matter upon delivery, and will shrink by 15 percent during storage. What price should the haylage receive?

Two adjustments are needed for haylage that has just been harvested and placed in storage. The first adjustment should account for shrinkage during the storage period, and the second should adjust for moisture differences between hay and haylage.

#### Sample Calculation to Estimate the Value of Wilted Alfalfa Intended for Haylage Compared with the Price of Dry Hay

| | | |
|---|---|---|
| **1.** | Current market price per ton for alfalfa hay | $200 |
| **2.** | Typical % DM of hay (as a decimal) | 0.90 |
| **3.** | Divide line 1 by line 2 to get the value of 100% dry matter hay in the market | $200 ÷ 0.90 = $222.22 |
| **4.** | Enter % DM of wilted alfalfa (as a decimal, in this case, 45% DM)* | 0.45 |
| **5.** | Multiply line 4 by line 3 to get the value of wilted alfalfa per ton | 0.45 × $222.22 = $100.00 |

* The dairyman preserving the alfalfa as silage should be aware that further shrinkage occurs during the ensiling process in addition to the moisture loss. Typical shrinkage (% weight loss between wilted forage and "as fed" haylage after fermentation) is 15%.

## The Alfalfa Haymaking Process

Haymaking is a four-step process. (1) It begins with cutting, which is usually done with a 12-, 14-, or 16-foot (3.6-, 4.3-, or 4.9 m) swather. (2) After a few days, the partially cured hay is raked to turn the windrow, and usually two windrows are combined or laid side by side. This procedure hastens the curing process and improves the efficiency of the baling operation. This is sometimes repeated when curing conditions are poor or when it rains. (3) After the hay has dried sufficiently, it is baled. (4) Finally, it is hauled to the edge of the field (roadsided) and stored until it is transported, sold, or fed. One of the most critical aspects of harvesting is drying the cut alfalfa to a point where it can be safely baled. The drying process and factors that influence drying rate are discussed below.

### Hay Curing

Even though the West is blessed with generally good curing conditions, there are times when weather conditions make haymaking a challenge. Rapid, uniform curing is important to minimize quality losses caused by bleaching, respiration, leaf loss, and rain damage. It also improves subsequent yields by reducing the effect of windrow shading, lessening traffic damage to regrowth, and allowing timely irrigation after cutting.

The moisture content of alfalfa growing in the field is generally from 75 to 83 percent. The drying rate of cut alfalfa depends on environmental variables, including 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 use management practices that accelerate the drying rate, considering weather and other factors. To determine which management practices would be most effective, it is helpful to understand the alfalfa drying process, which takes place in two phases. The drying rate during each phase is governed by the resistance to water loss from the plant (Fig. 14.4 explains various resistances to moisture loss). The first phase, or rapid-drying phase, accounts for approximately 75 percent of the moisture that is lost during the curing process and requires only 20 percent of the total drying time. The stomata (leaf pores) are wide open, and moisture is lost 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 stomata close. Stomatal resistance increases immensely and drying rate depends on cuticular resistance. Compared to moisture loss in the rapid-drying phase, moisture loss is extremely slow in the slow-drying phase. In fact, the drying rate in this phase is 1/100 of the initial drying rate. There are large differences between leaf and stem tissue in rates of drying, with stems being much slower.

### Mechanical Conditioning

To accelerate curing, many growers mechanically condition or crimp the alfalfa as they cut it. Mechanical conditioning has become a widely accepted practice. Most conditioners

**FIGURE 14.4**

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 leaf and stem surfaces |

lightly crush the forage between intermeshing rollers located behind the header of the swather. A number of designs are used, depending on the swather manufacturer. The intermeshing rollers are made of rubber or steel and crush or break the stems. The aggressiveness of crimping and the frequency of the crushing along the stem depend on the crimper design. The primary rationale for crimping is to facilitate water loss from the stems, bringing the drying rate of stems more in line with that of leaves. In theory, more aggressive crimping will have a greater benefit, but if the mechanical conditioning is too severe, shredded leaves may be lost, and the drying rate can slow if air movement is restricted in a dense mat of forage.

*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.*

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 and alfalfa yield. Conditioners should be set so that stems are cracked and crushed but not cut or shredded. Consult the swather owner's manual for proper conditioner adjustment.

### Maceration

The term "maceration" refers to severe mechanical conditioning that takes place at the time of cutting. The maceration process splits and shreds stems and abrades the waxy cuticle coating on plants. Stems are actually broken and split into numerous pieces, while the leaves and upper stem segments are crushed and pureed. As a result, there is a significant increase in the surface area of the plant exposed to the environment and a large reduction in curing time. After the alfalfa is macerated, it is pressed into a cohesive mat that remains intact and suspended on the alfalfa stubble. This way, leaves and stem segments don't fall through the stubble onto the ground. Using this system, curing time has been reduced to as little as 5 hours in studies conducted in the Midwest. The improvement in curing time is greatest under favorable curing conditions—warm, dry, sunny days. However, the difference in drying rate between macerated and nonmacerated forage is progressively reduced when drying conditions become less favorable. Under poor conditions, there may be little difference.

In addition to the more rapid curing rate of macerated forage, maceration also improves digestibility. Feeding trials have demonstrated an increase in digestibility of 10 percent or more for macerated forage. This means that even at the same fiber level, macerated alfalfa would be more digestible than conventionally harvested alfalfa. The improvement in digestibility is believed to be due to the actual rupturing of plant cells during maceration. The surface area of the forage is increased, and rumen microbes have greater access to the interior of cells, accelerating the digestion process.

Severe maceration, including the formation of a cohesive mat, is needed to achieve the benefits described above. There are different degrees of maceration. Some commercial macerators intensively condition the forage, but they do not macerate it to the same degree as the prototypes used in the initial research. Therefore, use caution when considering the purchase of a macerator-type harvester—drying rate and digestibility may not be improved to the same degree as was documented in initial research. In addition, macerated forage is not as visually appealing, due to the cut stems and off color, when compared with conventionally harvested alfalfa. This may impact marketing ability, especially when selling hay for retail or export markets. If severe macerating equipment were developed (like the original prototypes evaluated), special handling could be required, rather than just the use of a conventional baler.

## 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 to the alfalfa during swathing by mounting a spray boom to the swather header. 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 drying agents are most effective when the weather is warm and sunny. Unfortunately, under poor curing conditions, when enhanced drying is needed most (e.g., early spring or late fall), drying agents present little to no advantage. Furthermore, drying agents can present a problem when rain falls on treated hay, since treated hay reabsorbs water more readily than untreated hay. For these reasons and others (e.g., cost of the drying agents, the need to haul large volumes of water to and through the field for applications, and the relatively good curing conditions most of the year), drying agents are not believed to be cost effective and have not been widely adopted in the arid West.

## Swath Management

Wide windrows dry more rapidly than narrow windrows. This has been demonstrated in several California trials and in numerous trials throughout the United States. The extent of the advantage that wide windrows offer depends on the geographic area, time of year, and yield level. In general, wide windrows are most beneficial in late spring or early summer, when yields are high and day length is long (solar radiation is greater than in late summer or fall). 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, boundary-layer resistance is less with wide windrows, so they do not inhibit moisture movement to the degree narrow ones do. Wide windrows improve the uniformity of drying, which affects how soon after cutting alfalfa can be raked and baled. When a grower can safely rake and bale 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.

Some growers are reluctant to switch to wide windrows; they fear that, because wide windrows expose more surface area to the elements, extensive color loss from bleaching will result. Color, while not an important characteristic of the nutritional value of the hay, is important for some marketing channels, such as the export or horse market. Researchers have not observed a significant color difference, provided that the wide windrows are raked at least a day earlier than conventional windrows. 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 is usually done after the first drying phase. Little bleaching takes place 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. New swather designs have conditioners nearly as wide as the swather header, and growers can alter windrow width with a simple adjustment of a lever. Inexpensive windrow conditioner shields have also been developed that modify traditional swathers so they can spread windrows.

*Although wide windrows do expose more alfalfa, they usually can be raked and baled sooner, so exposure time is reduced.*

Because of their width, wide windrows must be raked before baling, and the alfalfa generally 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. There must be sufficient area between the windrows so that a tractor can pass through without running over the edge of either window, and the windrows should not be so wide that the rake cannot spread far enough to combine the two windrows. In addition, the windrow should not be so wide that it becomes too thin and patchy because this can cause excessive leaf loss during raking.

## Raking

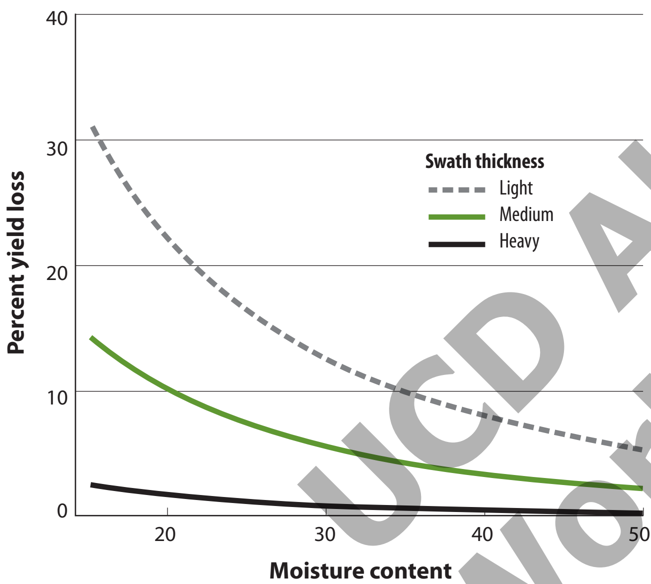
The purpose of raking is to expedite the drying process by transferring the alfalfa to drier soil and inverting the windrow. Inversion exposes high-moisture alfalfa from the bottom of the windrow to better drying conditions, increased solar radiation, and the effects of wind. Also, raking usually combines two windrows into one, improving the efficiency of baling and roadsiding. Raking is very effective in improving the drying rate, but it must be done at the proper moisture content; otherwise, excessive yield and quality losses will result (Fig. 14.5). Many growers rake alfalfa when it is too dry, leading to excessive leaf loss.

The optimum moisture content for raking is 35–40 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 rather than invert the hay and can actually slow the drying rate by restricting air movement within the windrow. Leaf loss associated with raking hay when it is too dry can be significant. In one study, when hay was raked at 20 percent moisture content, 21 percent of the leaves were lost; when raked at 50 percent moisture content, only 5 percent were lost (Table 14.3).

Hay raked on the same day as baling is too dry. The greatest loss is in the leaf fraction. Such loss significantly reduces the quality of the hay, since leaves are the most nutritious component of alfalfa. Research has shown that raking alfalfa hay that was too dry was 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 TDN. Baling when too dry resulted in a 5 percent yield loss. If alfalfa was both raked *and* baled too dry, the

### FIGURE 14.5

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






### TABLE 14.3

Moisture effects on 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 | 4 | 6 |
| At 12% moisture | 6 | 8 |

*Source:* Pitt (1990).

[1] Reported on a 100% dry-matter basis.

yield loss increased 10 percent over the raking loss.

## 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 (leaf material that is detached from the stem yet captured in the bale) and leaf loss (lost to the ground) will be excessive. Hay baled at too high a moisture content is subject to problems with mold, discoloration, and even spontaneous combustion (see Moisture Content for Safe Storage later in the chapter). 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 large 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 is stem moisture. How the hay is stacked after harvest also influences the moisture content at which alfalfa can be safely baled. A slightly higher moisture content at baling is sometimes safe, provided the alfalfa is stacked with an air gap between loads. The air gap facilitates more rapid dissipation of moisture from the bale. This is especially important for large bales, which weigh 0.5 to 1 ton (0.45 to 0.91 Mg).

## Moisture Content Estimates

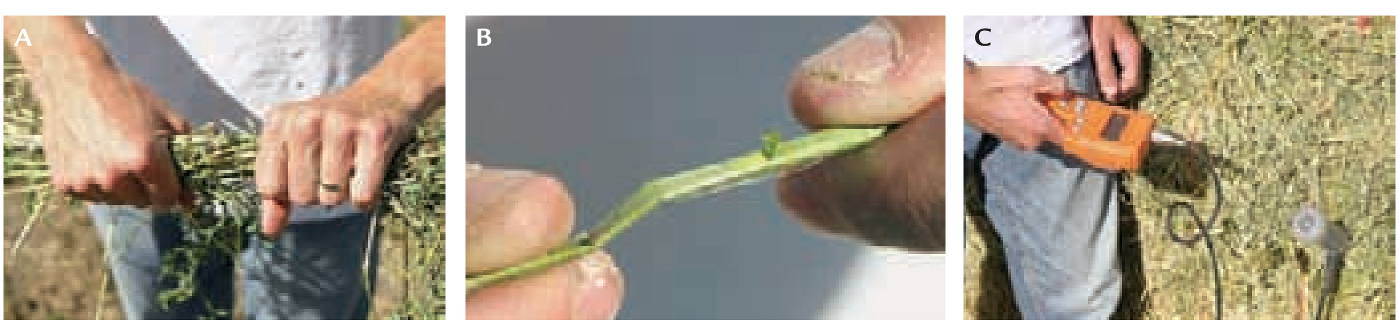
A simple and practical method to determine if alfalfa hay can be safely baled is to grab a handful of alfalfa with both hands and twist it by rotating your wrists in opposite directions. If the stems crack and break, the hay is usually dry enough to bale. This practice is not very precise, and it takes experience to develop proficiency.

The thumbnail test is a better method. Scrape an alfalfa stem with your thumbnail. If the epidermis, or outside layer, cannot be peeled back, the hay has dried sufficiently (Fig 14.6).

A moisture meter is also a valuable tool to evaluate the moisture content of hay. Resistance-type moisture meters are used as hand probes or mounted in the baler chamber for on-the-go moisture monitoring. Meters often indicate a moisture content that is slightly higher than the actual content, and should be used to predict general trends, not precise moisture. They measure stem moisture less accurately than they measure dew moisture. Although moisture meters do not provide a precise assessment of the true moisture content of

**FIGURE 14.6**

Three field methods for evaluating 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. Units are also available to monitor hay moisture in the bale chamber from the cab of a tractor.



hay, with enough experience, moisture meters are very useful tools for assessing whether it is safe to bale hay.

Moisture meters are ordinarily only used to assess the moisture content of baled hay. However, knowing the moisture content of alfalfa in the windrow before it is baled would help the grower determine whether the alfalfa is dry enough to bale. An improved method was developed by the University of Idaho: alfalfa from the windrow is packed into a section of PVC pipe and compacted to simulate a bale. The standard moisture meter probe is then inserted into the forage inside the pipe. This simple and practical technique improves the accuracy of windrow moisture testing.

A microwave oven is sometimes used to determine the moisture content of alfalfa hay. The technique is outlined in the silage section of this chapter. Although this method is accurate, it is more tedious than field assessments of forage moisture content and may not be practical when the grower needs to assess moisture at several locations in a field.

## Using Dew to Improve Baling Conditions

After alfalfa is fully cured, dew or high relative humidity is needed to soften the leaves. Otherwise, there will be excessive leaf loss (shatter) during baling. For example, there is usually ample dew in the Central Valley of California. However, sometimes (mostly in midsummer) dew or humidity is insufficient. Delaying the baling operation to wait for dew is undesirable; yield declines and leaf loss increases the longer hay is left in the windrow. In addition, waiting for dew postpones other necessary operations, such as irrigation, that are critical after cutting. Additionally, when baling is delayed, the amount of alfalfa regrowth increases, and the degree of traffic damage to regrowth increases accordingly.

Windrows can be sprayed with water to compensate for a lack of dew on days when humidity is insufficient to permit baling. Water sprayed on the windrow (approximately 40–50 gallons per acre [375–468 L $ha^{-1}$]) can improve baling conditions, reducing leaf loss. Depending on weather conditions, allow 10–30 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.

*Windrows can be sprayed with water to compensate for a lack of dew on days when humidity is insufficient to permit baling.*

## 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 bales can be reduced somewhat by allowing high-moisture bales to remain in the field until late afternoon to reduce their moisture content; then roadside 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 rapidly dissipate moisture deep within the bales.

Significant yield and quality losses can occur during storage. Studies have indicated dry matter losses of one 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 100°F (38°C), 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 14.4). When bale temperatures exceed 150°F (66°C), spontaneous combustion can result. This is most likely in hay with a moisture content over 30 percent and most often occurs with large (0.5–1 ton [0.45–.91 Mg]) bales.

Heating during the first month actually helps to dry hay (often termed the "sweat"). 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 excessive moisture are most likely to occur during the first month of storage. Although the majority of dry matter losses during storage take place in the first month, researchers in the Midwest found that losses continue at a rate of about 0.5 percent per month for the remainder of the storage period.

## Hay 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 from 18 to 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. What is more, preservatives are seldom 100 percent effective. The causes of erratic effectiveness are uneven application and areas of excessively high moisture content within a bale (often called a "slug"). In addition, propionic acid is hazardous to skin and eyes and corrosive to farm equipment. Buffered propionic acids are available to avoid corrosion problems. Alternatives to propionic acid include microbial inoculants and enzymatic products, but their results have been unsatisfactory in most university tests.

Most researchers conclude that using a preservative to allow high-moisture baling to reduce leaf loss is not usually cost effective. Preservative use may be justified if the product can be used selectively—only when rain is imminent or just for high-moisture areas of the field. As everyone knows, predicting rain can be very difficult, so it may not be practical to only use a preservative to avoid rain damage. However, equipment is now available that does enable the producer to only use the preservative in areas of the field where the alfalfa moisture warrants it. Moisture sensors in the bale chamber electronically control whether the preservative is applied and the rate of application. Using a preservative in this fashion may be economical for fields where moisture content varies widely.

## Cubing of Alfalfa

Alfalfa hay can also be processed into cubes. Cubes have never been as popular as baled hay in California and, over time, their popularity has dwindled. Except for the actual baling operation itself, most of the processes

**TABLE 14.4**

Problems associated with hay heating

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

*Source:* V. L. Marble

and procedures described above for baled hay also apply to cubes. The alfalfa crop is still cut with a swather and raked to turn and combine windrows. The hay can be cubed in the field or cubed with a stationary cuber. Field cubers process the hay directly out of the windrow in the field, but they are no longer manufactured. With stationary cubers, the alfalfa windrows are dry chopped and transported off the field to be processed.

The coarsely chopped alfalfa is compressed through mechanical dies with approximately 1.25 inches square (3.18 $cm^2$) dimension, with varied lengths. Thus, though called "cubes", most cubes are more rectangular in shape. One main advantage of cubing is that proper humidity for leaf retention is not important like it is for baling—dry conditions are preferred. Therefore, cubing works well in some desert environments where there is insufficient dew for baling. Water is added during the actual cubing process. Therefore, there is often less dust with cubes than with baled hay. A dust-free product can be especially important for horses. Care must be taken not to cube alfalfa contaminated with toxic weeds. Animals consume the whole cube and are unable to segregate the toxic weeds like they sometimes will with hay. The primary market for cubes is the horse industry or for export to foreign countries.

## Conclusion

Considerable effort is involved in producing a high-quality high-yielding alfalfa crop. While harvesting, curing, and preservation are the last steps in the production process, they can have a significant impact on the ultimate feeding value of the forage. Whether preserving alfalfa as silage or hay, the production practices outlined in this chapter should be followed to avoid significant losses. Key silage-making practices include excluding as much oxygen as possible by proper packing and sealing to minimize spoilage and making sure the forage is at the proper moisture content for ensiling. Key hay-making practices include vigorous conditioning, proper swath management (i.e., conditioning and windrow width) to promote rapid curing, raking at the proper moisture content to accelerate homogeneous drying of the windrow with minimal leaf loss, and baling the alfalfa at the optimum moisture content—high enough moisture for leaf retention while still low enough so that the hay can be safely stored with little risk of mold or heating problems. Employing these practices helps retain the potential feeding quality of the alfalfa while minimizing losses.

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