EQUIPMENT AND CHEMICAL ADVANCES IN HARVESTING AND STORING QUALITY HAY

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INTRODUCTION

In some areas of the country, many producers have gone to silage or haylage for storage of a portion of their forage. However, hay remains the most popular storage method for forage. Hay stores well for long periods and is better suited to cash sale and transportation over substantial distances than silage. Mechanical conditioning, which gained acceptance during the 1950's is probably still the greatest single change in hay harvesting and storage technology during this century. However, a number of other noteworthy changes and innovations have occurred in recent years which have helped to reduce the extent of losses during hay harvesting and storage.

The general relationship between forage moisture concentration at harvest and losses during the field and storage phases is shown in Figure 1. Harvest losses are greatest for very dry forage and are low for very wet material like direct cut silage. However, the latter is subject to excessive storage losses due to seepage and to quality deterioration. Storage losses are generally minimized by harvesting at low moisture levels. High moisture hay, baled between 20 and about 30% moisture has lower harvesting losses than dry hay but can suffer high storage losses and quality loss if not adequately preserved or dried.

Fig. 1. The relationship between forage moisture concentration at harvest and the amount of dry matter lost during harvest and storage.
The plethora of options available in haying equipment and in new products marketed for use in hay curing and preservation is such that making informed choices can be very difficult. Research information is not available on all of these new products, however, representatives of most of the categories have been studied.

**THE IMPORTANCE OF RAPID DRYING**

Rain damage becomes increasingly likely as the time required for field drying increases. The values in the box below show examples of the probability of rain occurring during the curing period for hay cured between 1 and 4 days. These values indicate a fairly high likelihood of rain in all cases but this is influenced to some extent by the way the calculations were made. Rainfall data from a location in southeast Iowa were used to calculate the probability of 0.1 inch or more of rain falling during each period. In determining these figures we assumed that no weather forecasting would be used to help avoid rain. Using weather forecast information, a producer should be able to improve the odds of making good hay somewhat over these levels. However, these probability values clearly illustrate the advantage of reducing the field time. Thus, the objective of hay curing is to remove the moisture as rapidly as possible within economic constraints.

**PROBABILITY OF 0.1 INCH OR MORE OF RAIN**

<table>
<thead>
<tr>
<th>Curing Time</th>
<th>Probability of Rain</th>
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<tr>
<td>4 days</td>
<td>74%</td>
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<tr>
<td>3 days</td>
<td>62%</td>
</tr>
<tr>
<td>2 days</td>
<td>45%</td>
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<tr>
<td>1 day</td>
<td>19%</td>
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**THE DRYING PROCESS**

When plants are growing, it is to their advantage to limit moisture losses. They do this in several ways. The outer surface of plants is covered with a waxy layer called the cuticle. The cuticle is very effective at limiting the loss of water. Figure 2 shows a generalized view of the outer surface of a leaf epidermal cell with the cell wall itself and the cuticle that covers its outer surface. The great majority of water that plants use when they are intact and growing moves out through pores called stomates in the outer layer. Stomates can be opened or closed as necessary to control the movement of water and gasses from the plant. Stomates are found mostly on the leaves and although they are very numerous, cover only 1-2% of the total surface area. These well developed systems for restricting the loss of water in growing plants cause problems in obtaining fast hay curing. Due to all of these factors, moisture loss during hay curing has to distinct phases. The first and the most rapid phase covers the first 20% or so of the total drying time but accounts for up to 75% of the total water loss (Figure 3). During this phase, water is lost from leaf surfaces and through open stomates. However, after moisture concentration reaches about 60%, the stomates close and drying rate slows drastically (Jones and Harris, 1980). Of course, moisture is also lost through the cut ends of the stems but
this is not very effective. Mechanical conditioning is effective because it physically breaks this cuticle layer which allows additional water loss through this otherwise nearly waterproof layer. Figure 4 illustrates the kind of improvements in drying that can be obtained by crimping or crushing alfalfa hay. A good conditioning job is critical to rapid drying.

Fig. 2. Cuticle covering the outer surface of leaves.

Fig. 3. Alfalfa drying curves under excellent and poor drying conditions (From Hill et al., 1977).
Environment strongly affects hay drying. High levels of solar irradiance, low humidity levels and wind speeds of 10-15 mph are desirable. The data shown below illustrate the impact that differences in relative humidity can have on the time required for hay curing. The curing times shown are hours of daylight and do not include the dark period when no drying occurs. We can take advantage of all the sun that is available by making the swath as wide as possible, covering 75% or more of the surface area. If the soil is wet, it may be best to make a slightly narrower swath to let the bare area dry and then turn the hay after it dries on top. Tedders, used just after cutting, can help to increase the interception of sun energy by spreading the hay over the entire area. It has been shown that tedding is effective in hastening the rapid, early phase of drying, but not the slower, last phase of drying. Tedding after the hay has wilted to 60% moisture will redistribute clumps and improve the uniformity of moisture concentration in the final product. Don't ted hay that has dried to 50% moisture because that can increase DM losses and is not effective in increasing drying rate (Dernedde, 1980; Jones and Harris, 1980). Tedders are useful in breaking up windrows of rained-on hay to allow for redrying. Because of the shatter losses that can occur in dry hay, raking should be done at moisture levels of 40% or more (Figure 5).
Potassium carbonate ($K_2CO_3$) has been widely studied in recent years as a chemical conditioning agent to hasten hay drying. This material as well as related compounds like sodium carbonate increase drying rate when applied in water solutions at the time of cutting. Apparently they act in some way to render the cuticle layer less restrictive to water movement. Figure 6 shows a typical response of alfalfa to $K_2CO_3$ treatment. These data were obtained under controlled conditions but they serve to illustrate the impact that this technology can have on alfalfa drying. The body of field research with potassium carbonate in recent years indicates that the response is greatest on cuts other than the first and under conditions of lower rather than higher humidity. The latter situation is not surprising since we depend upon the air surrounding the hay swath to remove hay moisture. If this air is already near its moisture holding capacity, moisture moves out of the hay less rapidly. Of course, since mechanical and chemical conditioning act to some extent on the same barriers to drying, they are not totally additive in their effects. That is, the combination does not produce as high a drying rate as the sum of separate mechanical and chemical conditioning. However, it is important to emphasize that mechanical conditioning should be continued when $K_2CO_3$ is used as a chemical conditioning treatment. It seems that the conditioning process, especially with intermeshing rubber rollers, helps with distribution of $K_2CO_3$ over the entire stem (Rotz and Davis, 1985).

Earlier studies indicated that fairly high water volumes were necessary to insure good coverage, in the range of 40-50 gal/acre. These kinds of water volumes limit the use of this technique because of the weight and time factors involved. Recent work indicates that the use of an air-curtain sprayer using a rotary atomizer with a straight stream airflow could improve distribution to the point where water volume might be reduced to slightly less than 20 gal/acre. These authors used a 50:50 mixture of $K_2CO_3$ and $Na_2CO_3$ applied at the equivalent of about 4 lb/acre and got satisfactory results with alfalfa. Many products have components in addition to potassium and sodium carbonate. These additional components have generally not improved drying rates over potassium carbonate alone (Rotz and Thomas, 1985).
Sodium carbonate is not as effective as potassium carbonate but it is less expensive and is generally included as a component of chemical conditioning agents.

Fig. 6. Drying of alfalfa treated with potassium carbonate (From Wentz-Carroll et al., 1982).

PRESERVATION OF MOIST HAY

Under high humidity, relatively cool conditions, hay does not dry as rapidly as under low humidity high temperature conditions (Hill et al., 1977). A good corollary is found in the way in which tobacco leaves become moist and pliable under high humidity conditions. Likewise, under high humidity conditions hay may not be able to reach the 20% moisture level recommended for baling dry hay regardless of the time spent in the field. Figure 7 shows equilibrium moisture
concentrations measured for alfalfa hay over a range of humidity conditions at a temperature of 77°. At a relative humidity of 80%, this graph indicates that alfalfa would not dry below 25 to 27% moisture. It is because of this problem and in order to reduce the likelihood of rain damage that alfalfa hay is sometimes baled at moisture levels above 20%. Our data (Collins et al., 1987) comparing alfalfa hay storage in round and rectangular bales indicates that for storage without heat damage, alfalfa in round bales should be slightly drier (18% moisture) than similar alfalfa in rectangular bales.

The data in Figure 8 indicate the importance of proper preservation of moist alfalfa hay in order to maintain quality (Collins et al., 1987). As moisture concentration increased in alfalfa baled in large round bales without any preservative or drying treatment, the digestibility of the hay after storage decreased sharply. All of this hay was very similar in digestibility at the time of baling. This decrease in digestibility is directly related to the heating that occurs when hay is baled at elevated moisture levels. Microorganisms are responsible for this heating and the resulting increase in heat-damaged protein and molding can be very detrimental to quality. Thermophilic bacteria, the actinomycetes grow well at high temperatures and contribute to the attainment of very high temperatures that result in hay fires in some instances. The hay temperature information below shows temperatures at which fire danger becomes important. Temperatures well below

<table>
<thead>
<tr>
<th>HAY TEMPERATURE (°F)</th>
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<tr>
<td>70  110  150  190  230  270  310</td>
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<tr>
<td>PLANT RESPIRATION</td>
</tr>
<tr>
<td>FIRE DANGER</td>
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<td>FUNGI AND BACTERIA</td>
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<tr>
<td>HEAT RESISTANT BACTERIA</td>
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that level can still reduce quality significantly. This moist hay can be preserved by the addition of organic acids at the time of baling. Propionic acid has been widely tested as a hay preservative and has proven to be very effective when it is well distributed and applied at the proper rates (Sheaffer and Clark, 1975). The most common rate recommendations for applying organic preservatives to hay are shown below. These rates are calculated on an active ingredient basis. In products containing some water, this must be considered in determining the product application rate. The rate applied must be increased for wetter hay because of the importance of maintaining the level of preservative in the water contained in the hay.

<table>
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<tr>
<th>APPLICATION OF ORGANIC ACIDS TO HAY</th>
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<tr>
<td>Hay Moisture Level</td>
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<tr>
<td>(%)</td>
</tr>
<tr>
<td>20-25</td>
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<td>25-30</td>
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<td>30-35</td>
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Ammonium propionate is a buffered propionic acid material that is less volatile than propionic acid and is also less corrosive. The low pH of acid preservatives is involved in their effectiveness (Woolford, 1984) but it is not the only factor since ammonium propionate is effective even though it is less acidic. Formic acid, sodium diacetate, propionic acid and ammonium propionate were tested and all were found to be effective in the inhibition of fungi and actinomycetes when each organism was grown separately in culture. Research has shown that it is important to achieve good distribution of the material in the bale. Wet spots that
have more moisture than the application rate is adequate for can still result in moldy areas within an otherwise well preserved bale. In a field study using alfalfa from a small field (5 acres), moisture at the time of baling varied widely depending upon the density of the swath at a particular location (Figure 9). This study was conducted during mid-summer of 1988 so a large portion of the variability in moisture concentration was a result of differences in soil depth and consequently in the amount of growth present. This type of situation would cause multiple problems in getting the proper rate of preservative on all bales. The value obtained for baling rate (tons of hay/minute) is the basis for nozzle tip selection and pressure setting. Variation above and below that average will mean that some hay will receive more material than needed and other hay will receive less. Moisture levels ranged from 58 to 80% and averaged 69%. A propionic acid application rate of 19 lb/ton would be sufficient to obtain a rate of 3% of the average water content. However many of the bales were above 69% moisture and would require more material. It would be necessary to apply 28 lb/ton to insure adequate preservation of 99% of the bales from this field. These results point up the importance of wide swaths and tedding to help improve the uniformity of the moisture concentration.

OTHER PRODUCTS

A great number of materials are presently marketed for application to hay. Prominent among these products are microbial inoculants marketed for application to moist hay. Rotz et al. (1988) compared two such materials. Both included Lactobacillus plantarum along with one or more other organisms and one included protease and amylase enzymes. Alfalfa was baled between 20 and 35% moisture with and without inoculant and as dry hay after reaching less than 20% moisture. Bales were evaluated after 45 days of storage. As is commonly found for untreated alfalfa hay, the higher the moisture concentration, the higher the temperature reached during storage. Over six trials, inoculant treatments failed to reduce storage temperatures or dry matter losses compared with untreated hay. Visual appearance was rated taking color and mold development into account. A score of 1 represented excellent hay and 10 represented hay that was dark in color and very moldy. Inoculated and uninoculated hay both had higher scores for discoloration and moldiness with increasing moisture concentration. Bacterial inoculants have proven effective in some situations with wilted silage, especially in early season and after frost when the population of fermenters present on the plant may not be adequate. However, I am not aware of any published data demonstrating that these products are effective with moist hay.

KNOWING THE MOISTURE LEVEL

Clearly, it is critical that we have dependable information on the moisture concentration in the hay in order to be sure of adequate storage if it is dry hay or that the preservative rate is adequate if preservatives are being used. A microwave oven is an excellent method for determining hay moisture. A 50-100 gram sample should be weighed and dried for 6 minutes. After that time, check the sample to see whether additional drying is necessary. If so, heat for 2 minutes and recheck. When the sample is dry, it can be reweighed and the moisture concentration calculated. Electronic probe testers are also available for field use in moisture determination. Of the units tested, the "Delmhorst" moisture unit did the best job of predicting actual oven moisture determinations. Figure 10 shows the relationship between oven and probe moisture values (Henson et al., 1987). Based on the variation we
found between measurements on the same bale, it would be necessary to take 12 readings to estimate moisture concentration within ±2%. Also, although the correlation with actual oven moistures was very good, the probe reading was not identical to the actual moisture concentration. At about 17% moisture, the two would give identical readings but above that moisture level, probe readings underestimated the actual moisture concentration. A rule-of-thumb system for estimation of hay moisture when a tester is unavailable is shown below (Hoard's Dairyman, 1987).

![Graph showing the relationship between oven moisture and Delmhorst meter readings.](image)

**Fig. 10.** Relationship between oven and Delmhorst moisture readings of alfalfa hay (* indicates the point at which both methods produce the same value) (From Henson et al., 1987).

**ASSESSMENT OF MOISTURE CONTENT OF HAY**

<table>
<thead>
<tr>
<th>Moisture Concentration*</th>
<th>Condition</th>
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<tbody>
<tr>
<td>30-40%</td>
<td>Leaves begin to rustle and do not give up moisture unless rubbed hard. Moisture easily extruded from stems using thumbnail or knife or with difficulty by twisting in hands.</td>
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<tr>
<td>25-30%</td>
<td>Hay rustles-a bundle twisted in the hands will snap with difficulty, but should extrude no surface moisture. Thick stems extrude moisture if scraped with thumbnail</td>
</tr>
<tr>
<td>20-25%</td>
<td>Hay rustles readily-a bundle will snap easily if twisted -leaves may shatter-a few juicy stems may remain</td>
</tr>
<tr>
<td>15-20%</td>
<td>Swath-made hay fractures easily-snaps easily when twisted-juice difficult to extrude</td>
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ON-THE-BALER AUTOMATIC MOISTURE MEASUREMENT

The same unit discussed above has been modified to automatically probe the bale inside the bale chamber between plunger strokes. These readings can be averaged and accessed continuously to allow moisture monitoring. We have the possibility of using moisture measurements of the bale either inside the bale chamber or just after tying to adjust preservative application rate continuously. If this could be accomplished it would insure adequate rates of preservative for every bale whether they needed more or less than the average.

BARN DRYING

Barn drying of moist alfalfa is definitely a viable alternative for the production of high quality hay. Parker et al. (1987) reported the results of evaluation of a solar-heated barn drying system for moist hay. Using fans to draw heated air from solar collectors on the barn roof, alfalfa hay stacked on edge seven bales high can be dried with excellent color retention and without mold development. Some mold development was noted at the floor in earlier trials because the duct through which the air enters the stack did not extent completely to the outside of the stack. However, placement of wooden framed to create air space between the floor and the bottom layer of bales eliminated that problem. Supplemental heat can be added during night hours using off-peak electricity, LP gas or possibly other fuel sources. This continues the drying process at night and improves turn-around time. Results to date indicate that drying adds about $15/ton to the cost of hay production. However the hay produced using this system is very high in quality and is competitive in the higher-valued horse hay market.

MECHANICAL DEWATERING OF ALFALFA HERBAGE

A technique was developed by which a standing alfalfa crop could be cut, macerated and pressed to remove about one-half of the initial weight (Ream et al., 1983). With that system, a silage material of 70% or less moisture can be produced from alfalfa with no field wilting (Collins, 1985; 1988). This material compares well with field cured hay in quality and a protein concentrate can be isolated from the juice which has a crude protein concentration in excess of 60%.

MACERATED FORAGE MATS FOR HAY PRODUCTION

The process discussed above is in commercial use as a stationary unit to aid with water removal for pellet production (Gastineau, 1974). It has not been developed, however, as a hay harvesting aid. An outgrowth of that program does have great potential as a rapid hay curing process. After cutting, alfalfa is macerated and pressed into mats that are placed back on the stubble to cure. Plant juices and the random orientation of the particles bind the mat together during drying. Drying proceeds extremely quickly because the cuticular resistance has been severely reduced by maceration. These mats can dry to 20% moisture in 4-8 hr, thus making it possible to mow and bale on the same day (Shinners et al., 1987). The average particle length in the mat is 0.2-0.4 inches.
REFERENCES


Hoard's Dairyman. 1987. Determining hay moisture is an art and science. 132:220.


