

HARVESTING HAY FOR HIGH YIELD AND QUALITY- MORE ON BALE VENTILATORS AND OTHER HARVEST AIDS

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INTRODUCTION

In some areas of the country, producers store a substantial portion of their forage for winter feeding as silage or haylage. 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 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.

Developments in hay harvesting technology in recent years include bale ventilators, chemical desiccants such as potassium carbonate, chemical and biological additives at the time of baling, and swath and windrow management equipment such as tedders and windrow inverters.

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.

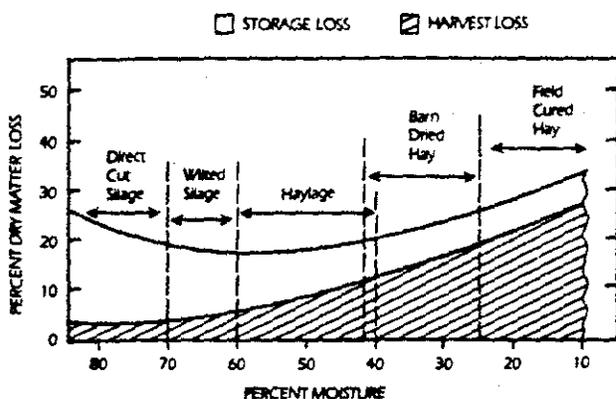


Fig. 1. Relationship between forage moisture concentration and field and storage losses.

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. Many options are 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 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. 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. During this phase, water is lost from leaf surfaces and through open stomates. British research indicates that after moisture concentration reaches about 60%, the stomates close and drying rate slows drastically. 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 effect of humidity and temperature on hay drying.

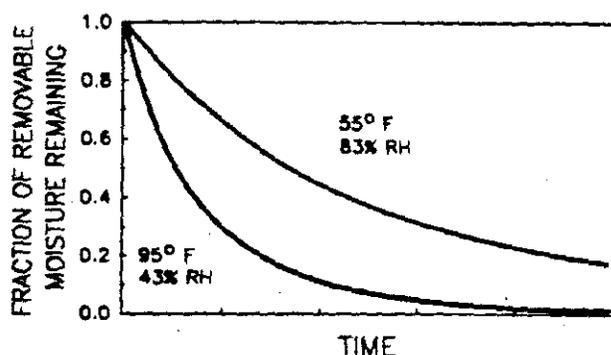


Fig. 2. Alfalfa drying curves under excellent and poor drying conditions (From Hill et al., 1977).

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

RELATIONSHIP BETWEEN HUMIDITY AND HAY CURING TIME

Humidity	Curing Time
40%	20 hr
50%	25 hr
60%	30 hr

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. 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 3).

Solar Radiation

About 20% of the incident solar radiation is reflected back into the atmosphere; the remainder is absorbed and aids in the evaporation of water. The sunshine intercepted by plants is dissipated mainly either by heating the forage material or evaporating water. However, the sun's radiation does not really penetrate very far into the hay windrow or swath. It has been estimated that less than one-half of the radiation penetrates beyond 1 inch depth. This is a major reason for the emphasis placed on maintaining the maximum swath surface area during drying. This increases the proportion of the forage mass that is affected by the sun's rays. Temperatures on the surface of a mowed swath may be as much as 40°F higher than that of the surrounding air on a sunny day.

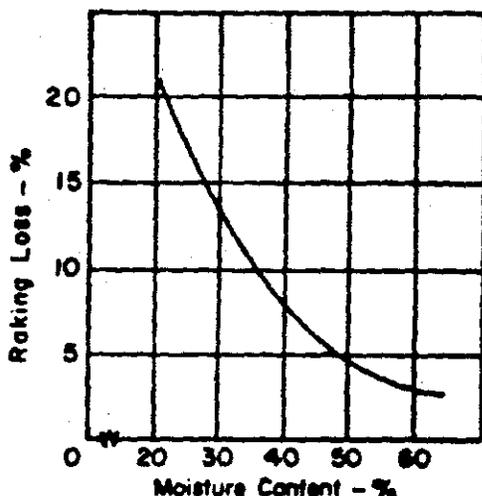


Fig. 3. Shatter losses during raking of alfalfa hay (From Moser, 1980).

The layer of air nearest the plant surface is called the boundary layer. The air nearest the surface of the alfalfa is more humid, and the air further away is less humid. Mixing this humid air with the surrounding, less humid air, improves drying because the moisture in the hay can move more readily into drier air. The

presence of a roughness layer, such as plant hairs, increases the thickness of the boundary layer and reduces turbulence. We now believe that this may be one reason red clover hay dries more slowly than some other species, especially if it is not conditioned well.

A good way to visualize the impact of weather on hay drying is that weather sets upper limit for how quickly a crop can dry. Other factors, such as forage species, mechanical or chemical conditioning etc. determine how close we come to achieving that potential.

Mechanical Conditioning

Mechanical conditioning hastens drying by physically breaking the cuticle layer discussed previously. This helps to defeat the plant's tendency to retain the water it contains. Mechanical conditioning is considered to be an effective way to improve the drying rate of all types of hay. In some cases, a good job of conditioning may actually halved the time required for hay curing.

Just after mowing, drying occurs primarily at surfaces exposed to the atmosphere and, thus, exposed to solar radiation. The humidity level within the swath is probably near 100% just after cutting, but as drying proceeds the humidity within the swath declines and eventually approaches levels in the outside atmosphere. Increasing surface area by making a wide swath helps to intercept more sunlight and hastens drying. Swath structure, and thus drying rate, may be adversely affected by severe crushing treatments due to increased difficulty in achieving and maintaining a low density swath. Tedding may aid in maintaining a loose structure and maximum surface area. Tedding should be done shortly after mowing or early enough in the day that some moisture remains in the leaf to prevent excessive losses.

Under high humidity, relatively cool conditions, hay does not dry as rapidly as under low humidity high temperature conditions. 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 4 shows equilibrium moisture concentrations measured for alfalfa hay over a range of humidity conditions at a temperature of 77°F. 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 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.

Chemical Desiccants

Potassium carbonate and sodium carbonate may be applied as a water solution to hasten hay drying. Legume hay benefits more from the application of these desiccants than grasses. Success with chemical desiccants is greatly affected by the achievement of good distribution of the material over the alfalfa stems. This requires 30 gal/acre or more of material per acre. The need for such a large volume of water for best application of these materials has been an important factor limiting their adoption. Research is under way with lower-volume alternatives for applying the chemical desiccants.

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. 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.

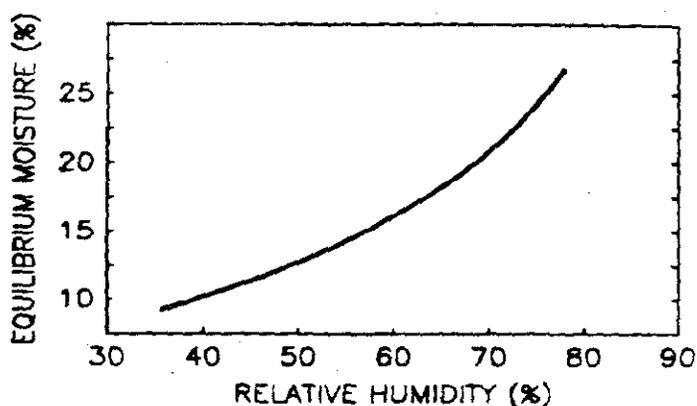


Fig. 4. Equilibrium moisture concentrations of alfalfa hay at different temperatures and humidities (Adapted from Hill et al., 1977).

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.

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. 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.

PRESERVING MOIST HAY

When hay is baled above 20% moisture steps should be taken to prevent the microbial growth that is responsible for heat damage and dustiness.

Respiration and Microbial Growth

Respiration and microbial growth, and some elevation in temperature during hay storage are normal and do not necessarily harm feeding value. Hay with more than 20% moisture may undergo excessive mold growth and heating that reduces both yield and digestibility compared with dry hay. Populations of fungi in stored hay peak after about 1 week of storage and this corresponds to the peak temperatures reached in the stack.

Health Effects

Mold spores contribute to colic in horses and are responsible for significant losses for this economically important industry. Breathing spores of the fungus Aspergillus fumigatus during the handling of moldy hay can cause farmer's lung, a sometimes debilitating disease in which the fungus grows in lung tissue. Hay with a significant amount of mold and mold spores can be utilized in cattle rations because these livestock are less sensitive.

Heat Damage

Heat damage may occur in moist hay as a result of plant and microbial respiration and chemical reactions. The moisture range in which the maximum amount of heating occurs is in the 20-40% moisture range for hay. This is close to the range in moisture for dry haylage at which excessive heating is observed. Dry hay does not heat excessively because it lacks the necessary moisture to support microbial growth. Plant enzymatic activity and microbial growth can elevate temperatures to 160°F within a few days. When the temperature goes above this level, it becomes too hot for continued microbial growth and further heating results from chemical reactions. These reactions are responsible for raising the temperature to levels at which spontaneous combustion may occur.

HAY TEMPERATURE (°F)

70	110	150	190	230	270	310
---FIRE DANGER---						
PLANT						
RESPIRATION-						
FUNGI AND BACTERIA-						
HEAT RESISTANT BACTERIA-						

Heating during hay storage reduces forage quality. The extent of the heat damage is related to the color change during storage is related to the amount of heat damage in

composition during heating of hay or silage are detrimental to forage quality. When hay heats sufficiently to cause a very dark brown to black color, its protein may be nearly indigestible.

Moisture Loss During Storage

The evaporation of water dissipates the heat generated in moist hay. The thermal conductivity of dry hay is actually less than that of moist hay. Thus, as hay moisture declines due to heating, the transfer of heat to the outside air becomes less effective. Hay temperature may not rise sharply until most of the moisture has been evaporated. This heat generation in a mass of hay is caused by the growth of microbes that require oxygen. Because of the distance, the centers of large hay stacks tend to be low in oxygen supply and spontaneous combustion occurs outside this zone.

The data in Figure 6 indicate the importance of proper preservation of moist alfalfa hay in order to maintain quality. 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

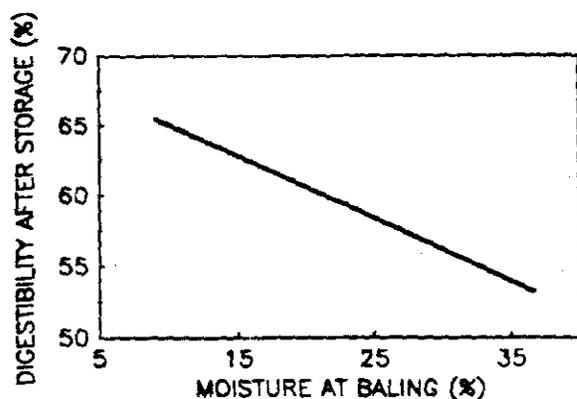


Fig. 6. Relationship between moisture level at baling of alfalfa hay and hay digestibility after storage (From Collins et al, 1987).

below shows temperatures at which fire danger becomes important. Temperatures well below 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. 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.

Hay Additives

Additives are sometimes used to aid in the preservation of hay above 20% a by preventing microbial growth during storage. Materials shown to be effective in the preservation of moist hay include sodium diacetate, propionic acid, ammonium propionate, urea, anhydrous ammonia and others. In addition to control of microbial growth, some materials, such as ammonia and urea, may also enhance forage quality by increasing crude protein concentration and increasing fiber digestibility.

The amount of propionic acid that needs to be applied to ensure acceptable control of microbial growth is greater for hay that is higher in moisture. Apparently, the critical factor is to maintain the necessary concentration of propionic acid in the water contained in the hay. Thus, hay with more moisture requires more organic acid for preservation. Hay heating and molding can be controlled by the application of rates as low as 6 lb/ton for 25% moisture hay under controlled conditions but under field conditions about twice that rate is needed to ensure preservation.

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 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.

APPLICATION OF ORGANIC ACIDS TO HAY

Hay Moisture Level (%)	Application Rate ---(lb/ton)---
20-25	10
25-30	20
30-35	30

Bale Ventilators

Bale ventilators are devices attached to the plunger face on a rectangular baler so that a hole is made through each flake as it is compressed in the bale chamber. Figure 5 below illustrates how the ventilators work to make a hole that should be continuous in the completed bale. Research done in Michigan with alfalfa at moistures ranging from 16 up to 25%, over a number of trials, ventilated bales were generally not different from unventilated bales. For example, at 20% moisture unventilated bales had 33.9% ADF and 20.4% Crude Protein coming out of storage compared with 34.3% ADF and 19.7% CP for ventilated bales made under the same conditions.

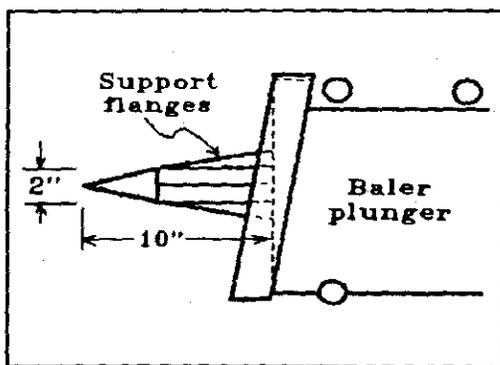


Fig. 5. Arrangement of the bale ventilator on the baler plunger face (From Rotz et al., 1993 AFGC Proceedings).

In one trial, Michigan researchers (Rotz et al., 1993) did find that acid detergent insoluble nitrogen levels were reduced, indicating less heat damage in ventilated bales. Since internal stack temperatures measured at the same time were not different for ventilated and unventilated bales, the basis for this response was not clear.

Research done at the University of Kentucky in 1992 indicated no significant response to ventilation of alfalfa bales at moistures between 17 and 22% (Table 1).

Table 1. Response of alfalfa hay in small rectangular bales to ventilation (1992 Data).

Moisture	HOLES	IM	FM	DUST	DEN	CP	NDF	ADF	DMD	DML
Moist	HOLES	21.5	13.6	4.56	6.2	18.4	51.1	36.5	65.5	6.0
Moist	NO HOLES	20.4	14.1	4.13	6.8	18.5	51.3	36.8	65.2	6.6
Dry	HOLES	17.6	15.3	1.95	5.6	18.3	49.9	36.0	65.4	3.7
Dry	NO HOLES	17.1	14.8	2.06	6.4	17.6	50.7	36.2	64.9	2.9

IM = Initial Moisture Concentration (%)

FM = Final Moisture Concentration (%)

DUST = Dustiness rating (1=lowest; 10=very dusty)

DEN = Density in lb/cubic foot;

CP = Crude Protein (%)

NDF = Neutral Detergent Fiber (%)

ADF = Acid Detergent Fiber (%)

DMD = In vitro dry matter disappearance (%)

DML = Dry Matter Loss during storage (%).

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. Michigan researchers 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.

Variation in moisture and uneven distribution may limit the effectiveness of hay additives. Variable moisture concentrations increase the difficulty of proper preservative application since higher rates are generally needed to preserve wetter hay. In a Maryland study, individual bale moisture concentrations of hay averaging 40% ranged from 33 to 45%. Poor distribution of propionic acid within the hay may allow the development of some species of fungi. When insufficient rates of propionic acid are applied on some portions of the hay, this may allow the growth of certain organisms that are able to utilize propionic acid as a food source, leading to further deterioration.

Moisture Variation Within The Field

Research has shown that it is important to achieve good distribution of the material in the bale. Buffered products have the benefits of being less volatile than acid products, however with that advantage comes the problem that these materials do not move around to equalize within the bale. Some very volatile products like ammonia move so well that the anhydrous ammonia can simply be released within a stack of hay and will diffuse throughout the mass with a short time. Even the acid forms of organic

acids do not move that readily but the buffered forms remain where they are placed during the application process.

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. 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.

Measuring Moisture In Hay

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 typical home 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. This last step is repeated until no further weight is lost, indicating that the sample is dry. When the sample is dry, it can be reweighed and the moisture concentration calculated by the following formula.

$$\text{Moisture Content} = \frac{\text{Sample Weight Wet} - \text{Sample Weight Dry}}{\text{Sample Weight Wet}} \times 100$$

A system using regression charts with a microwave oven allows accurate determination of actual moisture with only one weighing and in a shorter drying time of 4 minutes. The shorter time is possible because the sample is not dried completely in this method. The weight after 4 minutes of drying is closely related to the actual moisture. The sample moisture is read from a chart showing columns for the microwave weight and the actual moisture.

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. 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.

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.

In the absence of testing equipment, hay moisture can be estimated using changes in texture visual characteristics during drying. The table below illustrates how this system works.

ASSESSMENT OF MOISTURE CONTENT OF HAY

Moisture Concentration*	Condition
30-40%	Leaves begin to rustle and do not give up moisture unless rubbed hard. Juice easily extruded from stems using thumbnail or knife or with difficulty by twisting in hands.
25-30%	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
20-25%	Hay rustles readily-a bundle will snap easily if twisted -leaves may shatter-a few juicy stems may remain
15-20%	Swath-made hay fractures easily-snaps easily when twisted-juice difficult to extrude

*Reproduced from Hoard's Dairyman 132, 1987.