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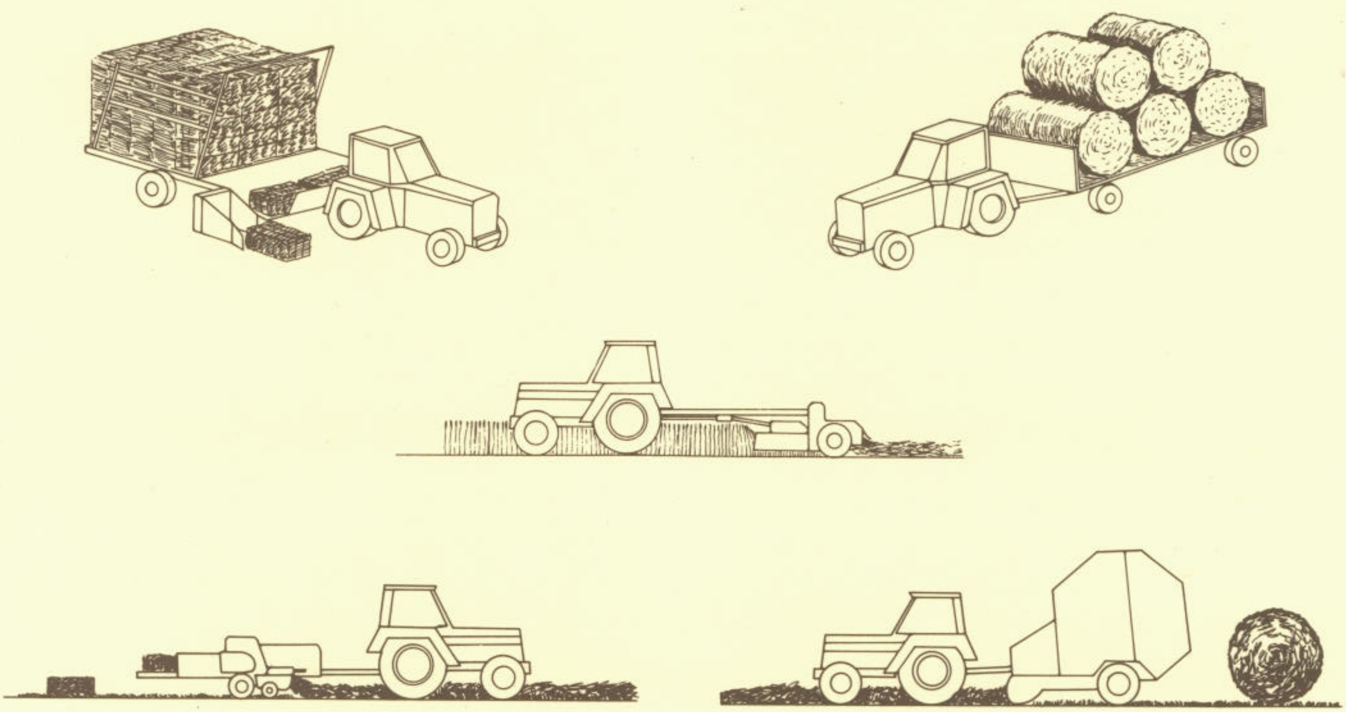
Modern Haymaking

Practices & Machines in Tennessee



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Modern Haymaking
Practices & Machines in Tennessee

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INTRODUCTION

Tennessee farmers have produced about two million tons of hay each year for the last 10 years. Average yield has been 1.6 tons per acre from approximately 1.3 million acres. The total value of the hay produced in Tennessee each year is about $120 million if the hay is valued at an average price of $60 per ton.

Hay acreage ranks third in Tennessee behind pastures (4 million acres) and soybeans (1.4 million acres). Alfalfa acreage has increased about 10 percent per year for the past five or six years. Presently, about 160,000 acres of alfalfa are grown in Tennessee. Commercial production of alfalfa may tend to increase acreage in the next few years.

Demand for high quality hay to feed one million beef animals, 210,000 dairy cows and 224,000 horses, ponies and mules will continue to keep Tennessee hay growers striving to produce high quality hay crops.

A shortage of reliable farm labor to harvest and handle hay in the past several years has forced many hay growers to mechanize their total hay production program. With hay equipment available today, total mechanization is possible from field to feeding. Good hay management requires a complete understanding of the many machines employed in the hay production process. Fundamental knowledge of machinery selection, operation and maintenance is essential to successful management of various hay machinery production systems.

The following information on haying machinery is intended to give both the novice and the experienced hay producer useful information relative to haying machinery. The section dealing with the systems approach will allow growers to evaluate different haying systems and select a "best" system for their particular situation. The section on cutting machinery will permit evaluation of several different cutting machines and will show advantages and disadvantages of each machine.

The section on conditioning machinery and methods will give information about hay conditioning machinery and other methods of conditioning that are presently available to hay growers. Treatment of hay crops with chemical drying agents, preservatives and ammonia is included in this section.

Baling machinery is discussed in a separate section, which describes the different baling options available to growers currently and gives valuable information for selection and operation of each system.

Transportation machinery deals with equipment used to handle large hay packages. Research figures on cost and capacity of several different systems are given.

SYSTEMS APPROACH

Many systems exist for harvesting, handling, storing and feeding forages. In all these systems, the procedures and equipment for each step must be properly matched to the other steps. With proper matching, the operations will be completed in an efficient and timely manner. Think of the necessary steps as links in a chain like that shown in Figure 1 for large package haymaking. For the system to function well, no weak links can be allowed. For example, field curing as shown in the figure is considered to be limited by the time required. In this case, artificial drying after limited field curing would correct the weak link.

Sketch a block diagram for your proposed haymaking system to see the steps needed. Are machine capacities evenly matched? If not, select different machines that will better match the system.

Consider now the operations and related equipment that comprise the links in the chain required for forage harvesting.

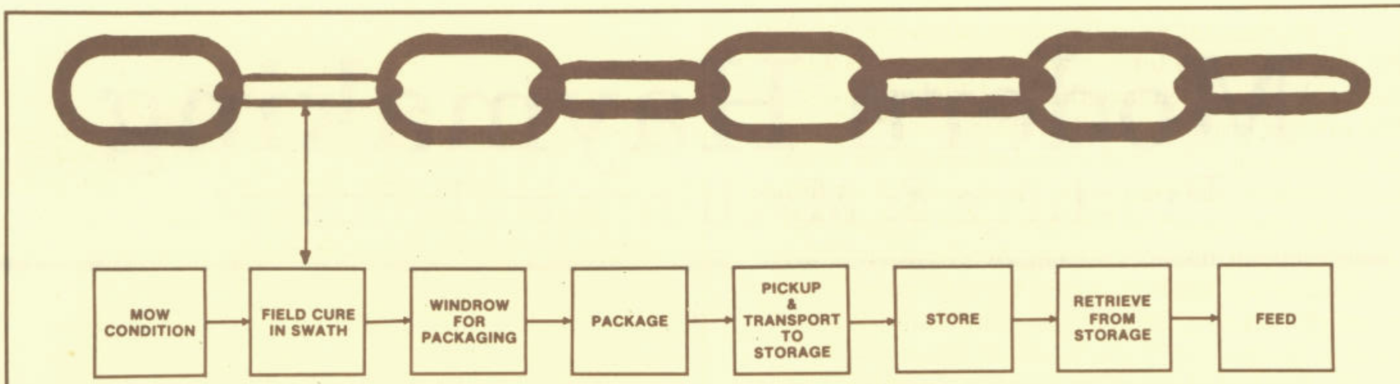

Figure 1. Block diagram for large package haymaking system.

CUTTING MACHINERY

Methods of cutting hay crops include the reciprocating sicklebar mower; the horizontal-rotor, flail-type mower; and drum and disk type mowers which have pivoted blades orbiting about the vertical axis of the drum or disk rotor assembly to which the blades are pivoted.

The sicklebar is an effective, relatively low-speed cutting device that requires low energy input. Cutting is by two-element shearing of the forage plants between the knife sections of the moving cutterbar and the fixed ledger plates fastened to the guards. With a 3-inch stroke of the cutterbar and 1,000 revolutions per minute (rpm) of the pitman crank or wobbleplate input shaft, peak knife velocity is less than 800 feet per minute (fpm), so little impact (single element) cutting occurs from the knife section acting alone. A knife velocity of 8,000 fpm is considered the lowest at which impact cutting of forages happens with dull blades. So, almost all cutting by the sicklebar mower is by two-element shearing (see Figure 2). Field losses and energy input requirements are lower for the sicklebar mower than for other cutting devices (see Table 1); however, it is subject to stoppages in dense, tangled or wet material, requires time consuming repair and maintenance, and limits forward speed of the cutting machine to the range of 3 to 5.5 mph (5-9 km/h).

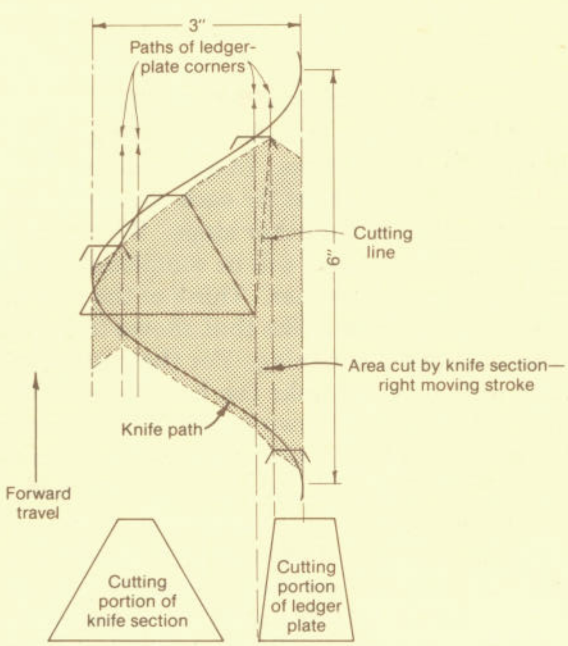

Figure 2. Graph of knife displacement versus forward travel for a conventional mower when operated with a forward travel of 3 in. per stroke (From Kepner, et al., 1972).

Table 1. Average Power Requirements and Field Losses in Alfalfa

Machine	Average power requirement per unit width of cut HP/ft. (kw/m) (1), (2)	Average field losses (Including those of fluted conditioner rolls) % of dry matter available at harvest (3)
Sicklebar	0.65 (1.6)	3.9
4-Disk Mower	2.08 (5.1)	5.9
2-Drum Mower	2.37 (5.8)	---
Flail Mower	6.05 (14.8)	---

(1) At 4.04 mph (6.5 km/h) forward speed.
(2) From Klinner, 1976.
(3) From Koegel, et al., 1985.

Horizontal-rotor flails can cut dense, tangled, wet crops on rough terrain without stoppages and require less maintenance than a sicklebar mower. The pivoted knives of the flail rotor swing back when an obstruction is hit, reducing damage to the knife cutting edges (see Figure 3). The knives sever forage stems by high-speed (8,500 fpm speed of blade tip), single-element impact cutting. Acceleration of the plant stems by the high-speed knives creates reactive inertia forces so great that the plant stems "appear" rigid to the moving knife; in effect, the plant stems are the "second element" in causing shear failure severing of the stems. Successive impacts of the pivoted knives on the severed stems being propelled to the rear of the rotor housing result in conditioning of the stems such that rapid drying occurs. However, short pieces of stem are often cut during the successive knife impacts and result in field losses when these pieces are not recovered in the raking and baler pickup operations. Double cutting and loss of the clipped material in the stubble result in losses 5 to 10 percent greater than those encountered with a sicklebar mower — fluted roll conditioner. Power requirements for the horizontal flail mower are high, compared to the sicklebar mower (Table 1).

Disk and drum mowers offer the impact cutting and blade protection advantages of the flail mower with less than half the power requirement and with less crop loss (Table 1). Both drum and disk mowers operate on the principle of pivoted blades orbiting about the vertical axis of the rotor assembly (see Figure 4).

Drum mowers have blades pivoted at the lower end of vertical, rotating drums supported only from the top. The supporting frame houses the drive train, which may be belts or gears. From two to four blades are pivoted to each drum assembly. Rotor diameter and speed give blade peripheral velocity in the range of 10,000 to 16,000 fpm, insuring impact cutting. Wheels and/or skid plates support the frame and maintain uniform cutting height. Cutting height is adjusted by tilting the frame forward or back. Drum rotation creates air currents that lift forage material before cutting and move the cut material to the rear. Drum mowers deposit the hay in windrows rather than in a wide, uniform swath.

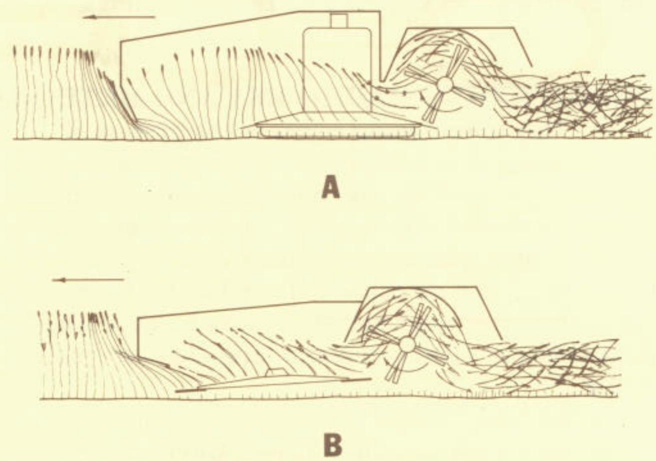

Figure 4. Drum (A) and Disk (B) mower-conditioner combinations.

Disk mowers have a series of oval-shaped housings, each supporting two oppositely placed, pivoted blades which have peripheral velocities of approximately 15,000 fpm. The disk units are supported from below by a thin cutterbar housing enclosing the shaft or gear train that drives the units in synchronized rotation. Skid shoes support the cutterbar, which is tilted forward or back to regulate height of cut. The severed forage plants are deposited behind the cutterbar in a wide swath.

Stubble height is more variable with drum than with disk mowers because of the larger circle swept by the pivoted blades of the drums. Drum mowers require more power than disk units because of greater airflow generated by the spinning drums. The drive train is simpler for drum than for disk units. Disk mowers are more popular than drums, mainly because of the wide, uniform swaths left by disk units, rather than the windrowed swaths left by drum mowers.

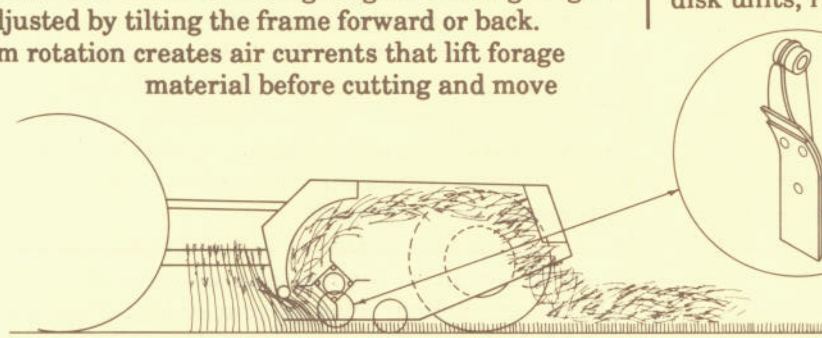

Figure 3. Schematic, cross-sectional view of a flail mower, showing enlarged details of pivoted flail knife (From Kepner et al., 1972).

Disk and drum mowers cut wet, tangled hay well and operate satisfactorily over rough terrain; these conditions clog and stop sicklebar mowers. Drum and disk mowers can be operated at ground speeds up to 15 mph. Power requirements are more than twice as great for these machines compared to sicklebar mowers of equal width-of-cut. Increased power is required by the cutting units, as shown in Table 1, and by the heavier frames and drives required for these machines.

CONDITIONING MACHINERY AND METHODS

Hay conditioning refers to the process of altering plant stems to permit faster moisture loss, which speeds drying. Hay may be conditioned using several methods. The most common form of conditioning began in the 1930s, with the development of a machine called a hay conditioner. These machines mechanically cracked and crushed plant stems to release moisture and facilitate faster drying.

In recent years, several other forms of hay conditioners have been developed. Chemical drying agents have been used to dissolve the waxy cuticle layer on the outside of plant stems. Removal of this layer removes a natural barrier to drying and permits a 30 to 50 percent decrease in drying time.

Tedders are a form of modified hay rake. These machines are used to stir and turn hay in the field after mowing. This action permits better air circulation among individual plants and turns the underside of the swath over to receive more direct solar radiation.

Swath inverters are used to rotate the mown swath after the exposed upper layers of the swath have dried. The wetter underside of the swath is then turned up to receive direct sunlight, along with increased air movement to carry away moisture.

Conditioning of hay reduces the time needed for field curing, thus reducing the probability of damage due to rainfall. A 30-50 percent reduction in drying time means that most Tennessee farmers can cut and bale hay in a 48 hour time period, as opposed to 72 hours or more needed to harvest unconditioned hay. The probability of 48 consecutive hours without rainfall is considerably higher than the probability of 72 hours or more without rainfall in Tennessee.

Extensive research has shown conditioned hay to have higher quality and greater palatability than unconditioned hay. Leaf loss from shattering is substantially reduced by conditioning hay, because the hay is baled before leaves become brittle. Reduced exposure to bad weather helps the crop to retain color, vitamins and nutrients. Coarse, stiff stems are crushed or cracked and become more palatable. From 1 to 4 percent of the potential crop yield may be lost in mechanical conditioning, depending upon crop conditions, conditioner aggressiveness and time of handling. Although mechanical conditioning may result in crop loss, the actual quantity of hay harvested may increase due to reduced field losses from less handling and reduced exposure to bad weather.

Conditioning is most effective on coarse-stemmed, leafy hays. Legume hays such as alfalfa and clover are particularly well suited to conditioning because their leaves become very fragile when dried. Conditioning of fine-stemmed grass hays is also beneficial, especially where weather damage could occur before the hay can dry naturally.

MECHANICAL CONDITIONERS

For best results, hay should be conditioned within 15 to 30 minutes after cutting, before wilting begins. Wilted stems are too flexible and will not split open easily for rapid drying. Three basic types of mechanical conditioners are currently used.

Crimpers consist of two corrugated rolls which mesh like gears and crack plant stems at intervals of 1 to 3 inches. This crimping action opens the stem in short, connected sections for faster drying.

Crushers consist of two rolls which may be metal or rubber or one of each. Different roll configurations which affect the type of stem crushing action are available. Both rolls may have a smooth surface or one roll may be smooth and the other roll may be ribbed. Some research has shown that crushed hay dries faster than crimped. So, some manufacturers use molded rubber rollers with meshing helical flutes that provide both a crimping and crushing process to condition the hay.

Recent research (1986) at Louisiana State found that intermeshing rubber rolls cut the drying time in half when used on ryegrass and bermudagrass hay.

Flail type conditioners and abrading conditioners employ a scuffing action to remove the waxy layer on plant stems. Speed of rotation and clearances of abrading shields are adjustable to give the most desirable conditioning action for the crop harvested. The conditioning effect is achieved mainly as a result of crop slip during acceleration, causing surface abrasion and scuffing. Because the ends of the plants are guided to meet the conditioning elements first, the cut ends of the plant receive more severe treatment than the upper (leafy) parts of the plant. Baffles reduce the velocity of the crop so that it falls gently to the ground.

A good indication of sufficient conditioning is when 90 percent of the hay crop shows evidence of conditioning action. Five percent or less of the leaves should show evidence of bruising. An easy way to evaluate the 90 percent guideline is to pick up 10 plant stems at random. Nine out of 10 of the stems should exhibit evidence of conditioning action. Excessive bruising of leaves or damage to plant stems may indicate conditioner action that is too aggressive. Adjustment should be made to reduce the conditioning action, thus reducing plant damage.

CHEMICAL CONDITIONING OF HAY TREATMENT WITH ANHYDROUS AMMONIA

Anhydrous ammonia has been used as a hay preservative in several regions of the United States, including the Southeast. Recommendations are that the ammonia be applied to hay at 30 percent moisture or less. Best results have been obtained at 25-28 percent moisture levels.

Ammonia is a fumigant; therefore, it retards organism growth and acts as a hay preservative. Ammonia also enhances the feed value of hay. Depending upon the moisture content of the hay, crude protein can be increased by about 5 percentage points and total digestible nutrients can be increased by about 10 percentage points. The practical moisture ceiling for ammonia enhancement is generally considered to be 30-32 percent by the majority of researchers in this area.

Ammonia enhancement is recommended only for medium to low quality forage, at rates of 1-3 percent ammonia treatment on a dry matter weight basis. Ohio State researchers recommend no ammonia-treated hay be fed to lactating dairy cattle. Several cases of "bovine hysteria" have been reported when dairy cattle were fed ammoniated hay. Animals experiencing "bovine hysteria" became hyperexcitable, run in circles, bump into walls and otherwise seem to lose control of body movement.

Excessive levels of ammonia in the feed have resulted in convulsions and death of sheep and cattle. Researchers have isolated a toxin called a fluorescent alkaloid that apparently is the cause of bovine hysteria.

Treating Hay With Ammonia

The most common method for treating hay with anhydrous ammonia is to seal the hay in plastic and inject the ammonia into the sealed area. Several variations of this method are used dependent upon the amount of hay to be treated.

Single large round bales are put into large plastic bags and sealed. A 3 to 4-foot length of black metal pipe attached to a hose from the ammonia source is inserted into the bag and one to three pounds of ammonia are applied for each 100 pounds dry matter weight of the bale. The pipe is then removed and tape is used to seal the hole in the plastic made by the pipe.

Treatment of several large round bales is accomplished by stacking the bales two high in a row long enough to accommodate the hay to be treated. This stack is then covered with plastic and the edges are sealed by covering with soil, sand or some similar material. The ammonia is then injected into the stack at one to three pounds for each 100 pounds dry matter.

Treated hay should remain sealed for at least two weeks in warm weather and about four weeks in cool weather.

DRYING AGENTS

Chemical drying agents were developed to reduce drying time in the field. This reduced field time lowers the probability of weather damage and reduces the need for mechanical manipulation of hay to aid drying. Mechanical manipulation results in loss of leaves and valuable nutrients each time hay is handled.

Modern drying agents are not desiccants, as were drying agents used years ago. Today's agents simply break down the waxy layer covering the stems of legumes. This process allows the water to leave the plant more rapidly. Once the waxy layer has been removed, the rate of drying depends primarily on atmospheric conditions.

Drying agents are not hay preservatives or mold inhibitors. Baling hay at a high moisture content will result in mold and heating even if a drying agent is used. Drying agents can be used in combination with organic acid preservatives to permit high moisture harvesting of hay.

Choosing and Using Drying Agents

The most prevalent drying agents on the market today are potassium carbonate, sodium carbonate, potassium hydroxide and potassium carbonate with methyl esters and surfactant. Michigan State research shows that potassium carbonate with sodium carbonate is more effective than either compound alone. Drying time is usually reduced by 30-50 percent in most cases. Recommended application rates are 30-50 gallons per crop acre, with a water solution containing a 3 percent amount of drying agent. (Thirty gallons of water would contain about 7-1/2 pounds of active ingredient.)

To apply the chemical to the hay crop, a spray boom is usually mounted to the hay conditioner so that the solution is sprayed onto the hay crop as the forage passes through the conditioner. Some producers mount nozzles above and below the flow of hay so both sides of the swath are treated.

Drying agents are not without some disadvantages. Chemicals can be corrosive to cutting-conditioning machinery and bales may be heavier. No university research has shown an advantage of chemically curing grass hays. Costs of treatment per acre of hay will vary depending upon chemical costs. In some cases, costs may run as much as $10 per acre. Producers should explore chemical sources for best prices and availability. Sources are listed in Table 2.

Table 2. Sources of Hay Wiling (Drying) Chemicals

Company	Phone	Product
Allen Manufacturing 180 N. Fruit Fresno, CA 93706	1-800-344-7300	Pro-Cure
American Farm Products 300 N. Huran Ypsilanti, MI 48197	313-484-4180	Pro-Dry
Arm & Hammer Distributors Church and Dwight Co., Inc. 469 N. Harrison St. Princeton, NJ	1-800-526-3563	Hay-Dry
Domain Inc. New Richmond, WI		Cut 'n Dry
Fen Products 1445 N. Gateway Blvd. Cottage Grove, OR 97424	1-800-526-3583	Conservit Econo Dri
Cenex/Land O'Lakes Minneapolis, MN	612-574-6666	Quick-Hay
Loveland Industries P. O. Box 906 Loveland, CO 80539	303-356-8920	Rapid Cure
Vigortone P. O. Box 1230 Cedar Rapids, IA 52406	319-393-3310	Bigordry

HAY PRESERVATIVES

Chemical hay preservatives permit baling of hay at moisture contents of 30 percent or less, instead of the usual upper limit of 20 percent. Preservatives used on 30 percent moisture hay will prevent mold formation and heating of hay that would normally occur at such moisture contents if a preservative were not used. Baling at higher moisture content will reduce leaf loss in legume hays. The resultant increase in dry matter yield and higher protein yield are advantages of chemical preservatives. Baling at higher moisture content will reduce the drying time in the field by several hours in many locations and reduces the probability of weather damage. Research at Pennsylvania State has shown an increase of about 400 pounds per acre of dry matter when chemical preservatives were used.

Acetic acid, propionic acid, ammonium isobutyrate, propionic-formic acid, propionic-acetic acid, isobutynic-propionic acid, ammonium propionate and ammonium bis-propionate are common chemicals used for hay preservation. Propionic acid has been the most common organic acid used for hay treatment due to its effectiveness when compared to other chemicals. Common rates of application are 10 pounds actual acid per ton of 25 percent moisture hay. At 30 percent moisture levels, a 20 pound per ton rate is needed. Rates of 20 pounds may prove to be uneconomical. Growers should make their own cost calculations and payback threshold determinations. Normally, a 10 pound per ton rate will cost around $7-8 per ton.

A liquid lactobacillus enzyme is also available on the market today to preserve hay. This bacteria type preservative "inactivates" bacteria present in hay that can cause spoilage. Cost of this enzyme is usually less than $1 per ton. However, USDA researchers say their tests on enzyme preservatives have not proven conclusive and they advise more testing and evaluation before recommendation of these materials.

As with other practices, use of hay preservatives presents some difficulties or undesirable situations. These include:

1. Organic acids are highly corrosive to metal machine parts and paint. Extra care is needed to lessen corrosion damage. Rinsing with clear water after use will nullify some of the damage to machinery; however, expect shorter overall machinery life when acids are used.

2. Success with hay preservatives is highly dependent upon thorough and uniform application of the preservative to the hay crop. In practice, this is a difficult goal to achieve due to variations in windrow

shape and size. The more uniform the application, the more successful the use of preservatives will be.

3. Accurate determination of the moisture content of the hay crop is essential. The rate of preservative applied is dependent upon the moisture content. Errors in moisture content assessment can result in failure to apply the proper rate of preservative. A good quality moisture meter is recommended for accurate analysis.

4. Hay bales will be heavier and more difficult to handle due to higher moisture content of the hay. Safety can become a factor when capacity of equipment reaches design limits, especially for large round bale equipment.

Table 3 below gives research data concerning dry matter losses, digestibility and peak temperatures for several treatment rates of propionic acid on 28 percent moisture content alfalfa hay.

Sodium diacetate is currently marketed as a mold inhibitor to prevent high temperatures in hay. This chemical is a good preservative. The manufacturer's literature recommends this chemical for hay crops of 25 percent moisture or less. It is marketed under the trade name of Crop Cure. Alfa-Save is the trade name for another hay preservative touted by the manufacturer to offer the advantages of propionic acid, yet none of the disadvantages. Alfa-Save is a buffered form of propionic acid which is non-corrosive and very safe to handle.

Table 3. Temperatures Reached and Dry Matter and Digestibility Losses Observed after Two Months Storage of Second Growth Alfalfa Hay, Approximately 28% Moisture

Treatment	Highest temper-ture (° F)	Dry matter lost (%)	Final digesti-bility (%)	Digestible dry matter loss (%)
Original Samples	---	---	70.9	---
Controls	115	15.1	59.6	20.1
0.02% Propionic Acid*	113	16.7	61.7	19.9
0.2% Propionic Acid*	100	13.2	61.6	17.3
0.5% Propionic Acid*	97	11.7	59.9	17.9
1.0% Propionic Acid*	91	7.6	65.5	10.3
Anhydrous Ammonia	90	9.9	65.5	11.2

** Percentages represent amount of chemical added as percent of total original weight of hay as it went into storage (Knapp, Holt, Lechtenberg, Purdue University).*

SIDE DELIVERY HAY RAKES

The primary purpose of a hay rake is to gather plants into a windrow after the plants have been cut. A continuous, uniform windrow is usually most desirable for pickup by a baler or forage chopper. A non-uniform windrow with lumps and hollow spaces can cause problems with the gathering units on balers and choppers.

Side delivery rakes 'sweep' plants into a windrow. Ideally, the leafy parts of the plant are on the inside of the windrow and the stems are on the outside, which helps to reduce leaf shatter and loss and promotes uniform drying of all parts of the plants. The best time to rake hay is usually as soon as the leaves are wilted but not dry enough to shatter. Legumes will usually begin to shatter around 45 percent moisture content. Since leaves contain a large portion of the plant nutrients, leaf loss means nutrient loss. Plants should be raked in the same direction as they were cut. This direction allows the rake teeth to contact the leafy tops of the plant for more positive plant movement. This also rolls the leafy part of the plant to the center of the windrow. Raking in the opposite direction from cutting will put the leaves on the outside of the windrow where further mechanical action can damage the plants.

Ground speed for raking will depend on the roughness of the ground, the type of crop and the type of rake used. Usually, a ground speed of two to five miles per hour is satisfactory. A faster rake ground speed normally produces a looser windrow while slower ground speeds give a tighter, more dense windrow.

Side delivery rakes normally have a maximum tooth velocity of 1.5 times the ground speed of the rake. Faster speeds can cause plant damage and leaf loss as well as possible damage to the rake. Ground speeds faster than eight miles per hour are not practical nor desirable. Rakes which have ground driven reels have a fixed relationship between ground speed and reel speed. Power driven reels should not be operated too fast for the ground speed selected (remember the 1.5 times ground speed rule).

Windrow density can be controlled to some extent by the tilt of the rake teeth on the reel. Tilting the leading edge of the tooth toward the front of the rake will produce a less dense windrow. Tilting the leading edge of the teeth to the rear produces a more dense or tighter windrow.

The teeth of the rake should penetrate the top of the plant stubble far enough to reach all the cut plants for movement into the windrow. Teeth set too high will leave some plants in and on the crop stubble. Teeth set too low can dig into the ground and flip soil into the windrow. The soil not only reduces hay quality but also damages balers and choppers from the abrasive action it causes while moving through the machine. Damage to the rake can occur when teeth are set too low and impact the ground. Broken or bent teeth usually result from this mistake.

Normal capacity of side delivery rakes is two to four acres per hour, depending on the forward ground speed.

HAY TEDDERS

Hay tedders were once widely used to speed hay drying, but efforts to reduce operating costs and increasing concern about field losses caused most farmers to stop using them.

Hay tedders are designed to stir or move hay in the swath to promote faster drying of the day. During the tedding process, the underneath side of the hay swath is relocated so it faces upward to receive solar radiation for faster drying time. The hay is also fluffed to facilitate better air movement through the hay stubble and cut hay for faster drying. The tedding action of several brands of hay tedders is adjustable from a slight, gentle tedding action to a very aggressive action, dependent upon the desires of the operator.

Recent studies show that tedder losses in alfalfa increase rapidly as moisture content decreases from 60 percent to 50 percent to 40 percent. Since most of the loss is leaves, hay quality is reduced even more. Experts suggest tedding of legumes such as alfalfa only when faster drying time can be expected to mean the difference between a small loss from tedding and major quality losses from imminent rain, leaching, exposure, and leaf loss as wet windrows are turned later to dry.

Legumes should be tedded soon after the hay is cut or when it is wet with dew or rain to reduce field losses. Legumes should not be tedded when moisture content falls below 50 percent.

The most advantageous use of hay tedders currently is for faster drying of grass hays. Grass hays suffer much less leaf loss from handling than do legume hays. Grass hays can be tedded two or three times if needed without excessive leaf loss.

Several companies now offer combination tedder-rakes which can, with few adjustments, be switched from tedding to raking. Growers with small to medium hay acreage might choose a combination machine over two separate machines for financial reasons.

BALING MACHINERY

Hay producers cannot realize top profits or obtain highest-quality feed unless they use the right harvesting system for their conditions. Of course, no harvesting system can meet the needs of all farms, simply because there are too many variable factors. Systems and equipment chosen should use available farm resources to the best advantage, and fit in with overall farm objectives. Most likely, the most important decision to make with respect to selection of hay machinery is whether the hay produced will be used on the farm or sold. In some cases, the producer may wish to both use and sell hay.

Some factors to be considered when choosing a hay harvesting system inolude:

* Type of crop
* Acreage and yield
* Type of livestock and feeding method
* Labor requirements
* Management abilities
* Capital available
* Flexibility of harvest system
* Operating costs per unit of material
* Market availability
* Existing storage structures
* Distance from field to storage and feeding areas
* Operator skills required to operate equip ment
* Timeliness factor relative to harvest quality

Some or all of the above factors, as well as unlisted factors, will have a significant effect on the harvesting system selection process.

SMALL PACKAGES VS. LARGE PACKAGES

Conventional bales are the most economical package for small hay volumes. Bales can be stacked, hauled and stored in a small space when compared to round bales and stacks. The feeding rate is easy to control simply by limiting the number of bales made available at each feeding. Surplus bales are relatively easy to market and transport when desired. Custom operators are usually available for harvest of small acreage where machine ownership is unjustified or undesirable.

Conventional bales do require more hand labor or more expensive machinery for mechanical handling from field to storage. Conventional bales will require inside storage or cover when stored outside to reduce spoilage losses.

Large round balers and stackers permit one-person operation from field to feeding. Package shape permits outside storage of round bales and stacks with little storage loss if a few simple proper storage procedures are followed. The economic loss from outside storage of round bales and stacks is low compared to the cost of providing storage facilities required for conventional bales.

Costs of operating large package systems are comparable to conventional baling at low annual tonnage production rates. Research at Iowa State in 1978 shows a total handling cost of about $32 per ton for conventionally baled hay and about $27 per ton for round bale hay at 100 ton per year production rates. This $5 per ton savings was maintained through production rates as high as 1,500 tons per year.

The same research shows a labor requirement of 2.52 hours per ton of conventionally baled hay as opposed to 0.65 hours per ton of hay with large round balers and 1-ton stackers.

Large round bales are difficult to transport long distances due to shape and density. Controlled feeding is difficult due to package size and waste can be excessive. Large round bales can be a serious safety problem if marginal size equipment is used for handling and if harvesting is accomplished on steeply sloping land.

CHARACTERISTICS OF BALING MACHINERY

Conventional Balers:

The most popular size bale is 14 inches by 18 inches by about 36 inches long. The length of the bale can be adjusted easily on most balers at the star wheel, which releases the tying mechanism to give a definite bale length. This pre-set bale length can vary about 8 percent shorter or longer depending upon the variations in the feed rate to the bale chamber. Windrows for baling should be made as uniform in size as is practically possible to give a uniform feeding rate to the baler. Smooth, continuous, even feeding of hay into the bale chamber will result in firm rectangular bales. The forward speed of the baler is determined by the windrow size and should be selected accordingly. Balers are more sensitive to rate of feeding than any other implement.

Bale densities depend on the material baled and adjustment of the density control. Bale density is adjusted on most balers by increasing the spring pressure on the bale slide. Bale densities for alfalfa hay will average about 12-13 pounds per cubic foot, while wheat straw bales will average about 7 pounds per cubic foot. Most legume and grass hay bales will average about 9-11 pounds per cubic foot.

Typical field capacity of conventional balers is around 170 bales per hour. In alfalfa hay this would correspond to about 9-11 tons per hour and about 3.5 tons per hour in wheat straw. Average baling capacity for most legume and grass hay will run about 7-8 tons per hour.

Typical baling losses at the baler pickup and baling chamber are about 3 percent. Total alfalfa leaf loss should be less than 4 percent but can go higher with overdry hay.

Round Balers

Manufacturers of large round balers offer a variety of sizes that produce bales from 4 to 7 feet in diameter and 4 to 7 feet in length. These bales can weigh from 600 to 2,200 pounds depending on the size and density of the bale. The moisture level of the crop also affects the density and weight of individual bales. Higher moisture crops require lower density baling to permit air circulation for adequate drying to prevent spoilage. Due to the variations in crop moisture content and the drying method employed, balers that can produce different bale densities are available.

Fixed chamber balers have a bale chamber that does not change in size. As hay enters the bale chamber after passing through compression rolls, a loosely compressed bale center or core is produced. As more hay enters and begins to fill the chamber, the outer layers of the bale are compressed more tightly around the looser core (see Figure 5). Flat belts, chains or rollers are normally used to compress the bale. The resulting bale from a fixed chamber baler will have a low density core and a higher density outer layer.

This type of bale is more suitable for artificial or forced air drying since air can flow through the looser material of the core to the center of the bale. Bales of this type normally have a density of about 4-7 pounds per cubic foot.

Variable chamber balers have a bale chamber that increases in size as the bale is formed (see Figure 6) to maintain a uniform pressure on the bale during the entire process of bale formation. Bales produced by this type of baler have a fairly uniform density

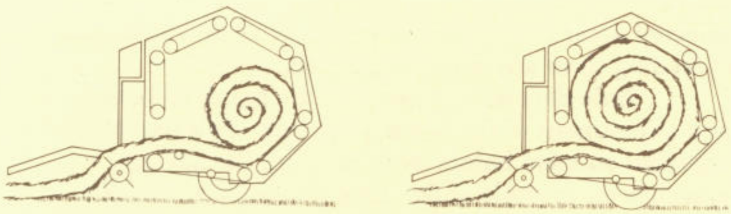

Figure 5. Bale formation in fixed chamber baler.

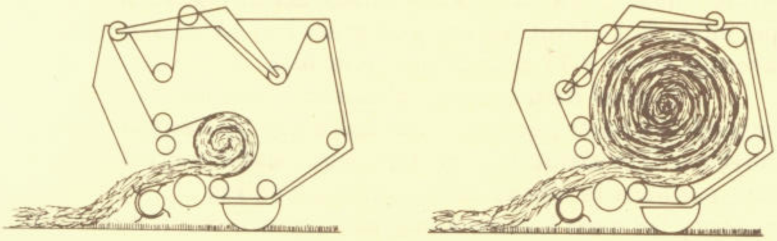

Figure 6. Bale formation in variable chamber balers.

throughout. Such bales are typically heavier than low density bales and normally weight about 9-12 pounds per cubic foot. These bales are typically more weatherproof than low density bales and shed precipitation better.

Adjustable density, variable chamber balers are available whereby the operator can begin baling individual bales at a given density, then vary this density for the outer layers of the bale. This permits different bale densities to accommodate crop moisture conditions and drying method to be used.

Table 4. Capacity of Three Hay Packaging Systems in Bermudagrass and Lespedeza Hay

Machine	Hay	Moisture (%)**	Tons/Hour Capacity
High-Density Round Baler	B*	18.5	11.28
Low-Density Round Baler	B	18.5	22.73
Low-Density Stacker	B	18.5	6.30
High-Density Round Baler	L***	12.3	6.63****
Low-Density Round Baler	L	12.3	18.47
Low-Density Stacker	L	12.3	4.03

* *Bermudagrass*

** *Baling capacities were 10-12 percent greater at higher acceptable moisture contents.*

*** *Lespedeza.*

**** *Time required to stop and wrap high density bales with twine reduced the capacity of this baler compared to the balers making low density baler packages which were not twine wrapped.*

Field capacity of two different round balers and low density stacker were evaluated in research in Tennessee by Robertson, et al., Table 4 gives the results of this work.

The power requirement to operate round balers is quite variable. Power requirements at the beginning of bale formation can be as low as 10 HP. However, as the bale size increases, the power requirement may rise to as much as 60 HP for 2,000 pound bales. A tractor of sufficient size and weight to handle the baler and a fully formed bale is essential when harvesting steeply sloping land.

Typical bale chamber losses for large round balers are from 5 to 15 percent. Under optimum conditions, losses will usually run around 5 percent. Bale chamber losses are higher in large round balers, primarily because the hay is manipulated for a longer length of time than in conventional balers. Chamber losses can be reduced by using heavy windrows baled at upper moisture limits.

Operators of large round balers should be trained in formation of properly shaped bales to reduce spoilage losses. Cone-shaped or barrel-shaped bales will not store properly and will suffer higher spoilage losses (see Figure 7).

Stack Wagons

Usually referred to as hay stackers, stack wagons are used to form large hay packages. In the past, manufacturers have offered several models of stackers ranging in size from one ton capacity to eight tons capacity. Currently, only one manufacturer is producing stack wagons. Stacks produced by these stackers vary in size from 7 feet inside x 10 feet long x 8 feet high to 12 feet x 16 feet x 15 feet in height. Densities of the stacks will vary from about five to 10 pounds per cubic foot.

As with large round balers, stackers can produce low density stacks or high density stacks, depending on the equipment used and the moisture content of the hay at harvest time.

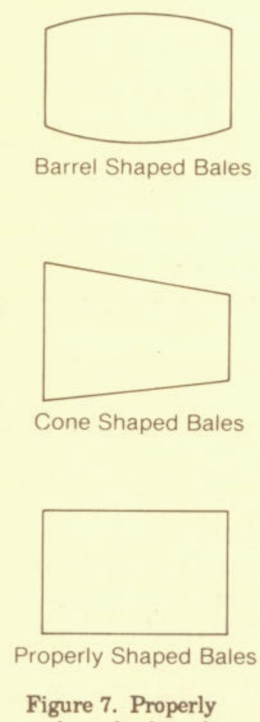

Figure 7. Properly and poorly shaped bales.

Two of the most frequent problems with stack wagons are due to operator inexperience and improper moisture content of hay. Both of these problems may result in stacks that do not store well and result in high spoilage losses. The generally recommended moisture content of hay for stacking is about the same as the proper moisture content for baling hay. Stacking hay at a moisture content drastically above or below the optimum may result in excessive spoilage losses during long term storage. Hay with too high-moisture content does not pack properly in the wagon. An improperly-packed stack may shrink during storage. Shrinking results in depressions or creases in the stack top. Such depressions allow water to enter the stack core.

Stacking hay at moisture content well below the optimum also increases field losses. Hay which is too dry does not pack well as it tends to fluff. A dry stack is particularly susceptible to wind damage before the thatch or crust forms on the top. Extra compaction can help compensate for dry hay, but is not a substitute for stacking at proper moisture levels. A general rule of thumb is not to stack hay if the moisture content is more than two to three points from the optimum moisture content for baling. Legume hays are considered safe for baling at about 18 percent moisture content while grass-type hays should be baled at moisture contents around 25 percent.

Stackers are commonly used to package corn stover. Stover stacks can usually be formed at moisture contents up to about 40 percent, but no more than 40 percent. Corn and milo stalks normally field-cure slowly, and cooler weather in the autumn permits stacking at higher moisture contents than for hay.

Large stack wagons have a field capacity of about eight tons or more per hour. Labor required for handling and feeding small stacks is about the same as for large round bales. Large stack wagons require only about half of the labor for harvesting and feeding as do small stackers.

One ton stackers can be more economical for harvesting and feeding over 50 tons of hay per year when compared to conventional baling systems. Small stacker and large round bale costs are about the same.

Power requirements to operate stack wagons range from about 30 horsepower for small stackers to 100 horsepower for large stackers. As with large round balers, operators should use tractors of sufficient size and weight to safely operate stackers on steeply sloping land. An eight-ton stacker full of hay can easily exceed 12-13 tons in weight

TRANSPORTING EQUIPMENT

Conventional hay bales are typically 14 inches by 18 inches by 36 inches or so in length and weigh about 50-80 pounds. Another common size is 16 inches by 18 inches by 36 inches in length with weights of 70-90 pounds. Due to the size and w eight of these bales, transportation does not pose as serious a problem as it does for large round bales and stacks weighing several hundred pounds. Conventional size bales can be handled by hand and can be transported in various numbers to accommodate the size of equipment available for transportation.

Large round bales and stacks are much more difficult to transport due to the volume, shape and weight of individual bales and stacks which may weigh as much a 10 tons each. In most cases, special equipment is required for transportation of these large package systems

Machinery for Moving Large Round Bales

Large round bale systems for handling hay have many attractive features; reduced labor requirements is one of the most attractive. The large size and weight of the bales does present a problem when transporting bales from one location to another location. Bale sizes range up to 7 feet in length and 7 feet in diameter with weights of 1500-1800 pounds are not uncommon.

Several systems for handling and moving bales are available and studies have been conducted to compare efficiency, costs, power sources and labor needs.Table 5 following compares 10 different bale moving systems and their respective features.

Safety is a major concern during transportation of large hay packages. Large round bales pose safety hazards due to the round shape of the bale and the heavy weight (1,000-2,200 pounds) of common size bales. Operators should read and study the publication on forage machinery safety to become fully aware of hazards involved in large package hay handling. Ground speeds of the 10 systems evaluated ranged from 6.5 MPH in the field to 22.5 MPH on the road with the self-loader on a pick-up truck. Operators should not attempt to operate at faster travel speeds than recommended by the manufacturer.

A major concern of many hay producers in addition to the hourly or daily capacity of transporters is the cost for various hay transport systems. Cost analyses indicate that one-bale transport systems are reasonable for production up to 100-125 tons of hay per year. Two bale systems work best for 50-250 tons per year. Multi-bale systems are better suited to 250-1,000 tons per year production.

Table 5. Comparison of 10 Hay Bale Moving Systems

System	Bales /Load	Power Source	Bales/Hour Capacity
1. 3-Point Hitch Unroller	1	tractor	4.3
2. 3-Point Hitch Fork	1	tractor	4.8
3. 2-Wheel Trailer Self-Leading	1	pick-up truck	3.9
4. Front-End Loader Fork Attachment	1	tractor	4.8
5. Front and Rear Tractor Loader	2	tractor	8.2
6. Bale Loader on Truck	2	pick-up truck	10.6
7. Dump Bed on Truck	2	pick-up truck	10.0
8. Multi-Bale Hauler	3	tractor	12.0
9. Multi-Bale Hauler	4	tractor	14.8

All systems require one person to operate.

Ground conditions and weather can be major factors in selection of transportation methods. Snow, mud, and ice can cause traction problems with some equipment. Tractors with cabs may be more suitable in cold, wet weather than pick-ups with 2-wheel or 4-wheel drive.

Machinery For Moving Stack Hay

All stacks tend to come apart if they are moved too soon after the stack is unloaded from the wagon. Therefore, it is best to wait at least 48 hours or longer before hauling newly-formed stacks out of the field with a stack mover. This delay allows the stack to settle and become tightly knit before it is moved. To permit time for proper settling, stacks may be hauled as they are formed in the stacker machine to one location in or close to the harvested field to prevent interference with other field operations. More time will be required for stacking with this method; however, moving time will be reduced later.

The most common problem encountered with

Table 6. Methods for Handling and Transporting Hay Packages

Description	Approximate Handling Capacity*	Approximate Price
	Tons/Hr.	
Trailer Type Mover for Single Roll Bale; Manually Operated Winch	2.0	600
Tractor-Mounted (3-Point Hitch) Mover for Single Roll Bale	4.41	250
Tractor-Mounted (Front-End Loader Attachment) Mover for Single Bale	4.41	250
Tractor-Mounted (3-Point Hitch) Mover for 1-Ton Stacks	7.2	900
PTO-Driven Roll Bale Pickup and Transport Trailer (3- to 4-Roll Capacity)	7.2-8.8	4500

* *Average transport distance of 0.8 mi.*

Table 7. Capacity of Low-Cost, One-Roll Transport Methods

Method	Capacity for different haul distances		
	0.5 mile	1.0 mile	2.0 miles
3-Point Hitch or Front-End Loader Attachment for Tractor	7.20	2.42	1.76
Truck Towed 2-Wheel Trailer Mover	2.98	1.98	1.65

stack movers is too much haste in loading and unloading. To increase hauling capacity, the operator may try to load and unload too fast. This allows stacks to split open and permits water to penetrate the stack core. Fast transportation over rough ground may shake the stack loose and make it subject to damage by wind and water. Fast transport, particularly under windy conditions, may lift the upper layers of hay at the front of the stack and cause hay loss and unnecessary spoilage if the hay is stored again after moving operations. Due to the weight of even the smallest stacks produced by stackers (one ton), special equipment is required to pick up and move stacks unless the hay stacker is used to transport stacks as they are formed. Stack movers are designed to move stacks from the field to the stack yard and/or to the feeding area.

The smallest stack movers are designed to handle 1 to 1 1/2 ton stacks and are integrally mounted on the tractor three-point hitch. Most of these fork movers have caster wheels to help carry the load and eliminate the need for heavy ballast on the front of the tractor.

Tilt bed trailers are used to move stacks weighing two tons or more. These trailers usually have flotation tires to permit travel on soft, wet ground. Drag chains powered by hydraulic motors or the tractor PTO are used to pull the stack onto the trailer.

For long distance hauling, truck mounted or towed movers are usually most efficient. Much time can be saved in long-distance hauling with these movers. Most of these units are designed to handle 6-ton or larger loads. These units are most popular with hay growers or buyers who handle large volumes of hay to be transported long distances.

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