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AG FACTS

FORAGE PRODUCTION AND USE

PERFORMANCE AND COST COMPARISONS OF HAY HARVESTING EQUIPMENT

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Choosing the best set of machinery for your forage harvesting system is a complex task. Today many alternatives are available for harvesting, processing and storing forages and each has advantages and disadvantages. The best system for your neighbor may not be best for you because each farm is unique. Factors that influence selection include farm size, farm layout, soil structure and fertility, farm terrain and current assets, just to mention a few.

The first decision to be made is whether you'll harvest your forage as dry hay (less than 20 percent moisture content, wet basis) or wet haylage (greater than 50 percent moisture content, wet basis). Most dairy farmers today produce both hay and haylage because the combination reduces the risk of crop loss and because there is a need for both in the livestock system. This bulletin will discuss the many alternatives available for hay harvest in the Midwest.

Cutting the crop

Several alternatives are available for cutting the crop. Mowing can be done with a cutterbar, rotary disk or rotary drum mower with or without some type of conditioning. Rotary disk and drum mowers are similar in design in that each cuts with a rotating blade. In a drum mower, the blade is suspended on the base of a drum; in the rotary disk mower, the blade is carried by a rotating disk. To reduce field curing time, most mowers are equipped with stem crushing or "conditioning" equipment. Conditioning typically reduces drying time by ½ to 2 days, with the greatest advantage occurring on first cutting.

Many types of mower-conditioners are available. Some of the major alternatives are: cutterbar mower with intermeshing rolls, cutterbar mower with non-intermeshing rolls, flail mower and conditioner, rotary disk mower with intermeshing rolls, and rotary drum mower with a flail or non-intermeshing rolls for conditioning. When adjusted properly, all of these mowers produce a similar effect on the drying rate of alfalfa. As shown later, the major differences are in field losses, machine capacity and power requirements.

Raking

Many growers today like to avoid raking by adjusting the mower-conditioner to lay the hay in a narrow swath. Drying rate is reduced, however, and field drying time may be increased one or more days. Three basic types of rakes are available: parallel-bar rake, wheel rake and rotary rake. Parallel-bar and wheel rakes are very common. The rotary rake uses teeth suspended from a rotating horizontal disk to sweep the crop into a swath.

Packaging

For packaging hay, the major alternatives in the Midwest are the rectangular baler and the large round baler. Hay cubers, 1- to 2-ton rectangular balers and haystack wagons are also available, but they are more suitable for other climates. The major advantage of the large round baler is that it permits rapid, one-person harvesting by eliminating much of the time and manual labor required for bale handling.

Handling and storing

Several alternatives are available for bale handling and storage for either rectangular or round bales. For rectangular bales, a thrower can be used on the baler to place the bales on the wagon in the field. Rotating several wagons allows hay to be hauled and unloaded in storage while the baling operation continues. Automatic bale wagons—which pick up bales from the field, stack, haul and unload them without manual handling—are another option.

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Round bales can be moved one at a time or in groups of four or five on a wagon. To haul one at a time, a spike or other gripping device is normally used on the rear of a tractor. A wagon is a more efficient means of moving large round bales, particularly when they are transported some distance. The round bale wagon has a mechanism for lifting a bale and placing it on the wagon with three or four other bales for transport.

Rectangular bales are normally stored inside a shed to minimize storage losses. Large round bales can also be stored inside, but they are often stored outside to eliminate storage costs.

COMPARISON OF FORAGE EQUIPMENT

When selecting forage equipment, some of the major factors to be considered are: field and storage losses, machine capacity, labor requirement, fuel requirement, tractor requirement, initial cost, and total cost of ownership and operation. Each of these factors will be discussed for each of the major alternatives available.

Losses

Losses occur in several ways during hay harvest and storage. Shatter losses are most visible as small particles (normally leaves) are stripped from the plants and lost. Respiration losses are the conversion of nutrients to carbon dioxide and water by plant and microbial enzymes. This is an invisible but sizable loss of nutrients. Rapid drying can reduce this loss. Rain causes leaching of plant material and a wet environment for microbial growth and respiration. Sunshine can bleach the crop, causing losses as well as nutrient changes.

Typical values for the total of all losses are presented in Table 1 for each machine operation. Losses can vary considerably, depending on crop and weather conditions. Values given represent averages over several years.

Losses with a cutterbar mower are about 6 percent of the crop yield. These losses are primarily due to poor cutting, which leaves a long stubble, and respiration, which depletes carbohydrates during drying. With a mower-conditioner, losses increase slightly because the rollers tend to strip some leaves. With a flail mower-conditioner, losses increase because small particles cut up by the flail are lost.

Raking losses are primarily due to shattering of leaves. Alfalfa hay should always be raked at a moisture content above 35 percent to reduce this loss. Parallel-bar rakes have lower losses because the rolling action of the rake tends to wrap leaves into the windrow. In contrast, the sweeping action of the rotary rake can strip leaves and drop stems more easily. The rotary rake will provide a fluffier windrow that may dry faster under some conditions. This type of rake is most satisfactory with grass hay.

Baler losses are primarily due to the shattering of dry leaves. Losses tend to be much higher for large round balers than for rectangular-type balers because the rolling action of the round baler tends to strip more leaves and lose other small particles. In some newer baler designs, an enclosed bale chamber or other method is used to recycle small particles that drop from the bale. With these improvements, losses with the two types of balers can be similar.

Losses during bale handling are normally very low. Losses with a bale thrower can be substantial as small particles are knocked and blown from the bale.

Storage losses for dry hay stored in an enclosed shed are consistently around 5 percent. These losses are due to microbial activity on hay during storage. When hay is stored outside in the Midwest without a cover, losses can increase considerably. Losses vary from about 12 to 50 percent, depending on weather conditions and other storage conditions.

Capacity

Field capacity is a measure of machine performance that indicates the amount of work a machine can complete in a unit of time, expressed either as acres per hour or tons per hour. Field capacity can vary considerably, depending on the size and shape of the field, the size and condition of the equipment, and the crop yield. Typical values are given in Table 1.

Rotary disk mowers have a higher capacity than similar sized cutterbar equipment. Because rotating blades are more resistant to plugging, rotary equipment can move faster across the field. Round balers have a higher capacity than rectangular-type balers. They can be operated at faster speeds, and they don't get held up waiting for transport wagons.

The capacity of bale handling systems varies considerably. For rectangular bales, three bale wagons with manual unloading can about match the capacity of a small baler. A small, automatic bale wagon has a slightly lower capacity. Moving large round bales one at a time gives a very low capacity, one-third to one-half that of a bale wagon.

Labor Requirements

Labor requirements are closely related to machine capacity. Most operations are performed by one person, so the labor requirement (worker-hr/ton of hay) is directly related to the work rate of the machine. In the case of transport of rectangular bales, the labor requirement is relatively high—three people are required to perform this operation (Table 1). Transporting large round bales one at a time with a bale mover also has a high labor requirement because of the large amount of time required. The advantage of this method is that one person can perform the operation, even though it may require several days. Automatic bale wagons have a comparatively low labor requirement because of their one-person operation and high capacity.

Tractor and Fuel Requirements

Tractor size required to perform an operation is an important, though often overlooked, factor in the comparison of machinery alternatives because tractor size can affect the total cost of an operation more than any other factor. Larger tractors not only cost more to purchase, but they cost more to operate.

Fuel requirements for performing various operations are closely related to tractor size because larger tractors use more fuel. Fuel requirements are also influenced by machine capacity. High capacity machines can do the work in less time and this may reduce total fuel consumed. Typical tractor and fuel requirements for major operations are listed in Table 1.

Tractor size is a consideration when selecting a mower-conditioner. Relatively small tractors (35 hp) can be used to operate a cutterbar mower-conditioner. Flail mowers require more power, and rotary disk mowers require even more. As tractor size increases, the fuel requirement goes up. The high capacity of the rotary disk mower-conditioner reduces the fuel requirement somewhat, however.

Larger tractors are required to harvest and handle large round bales. For bale handling, the larger size is required primarily for stability rather than power. This inefficient use of a large tractor increases the fuel requirement as well as the total cost of operation.

Machinery Cost

Perhaps the most important factor to consider in comparing and selecting equipment is the total cost of ownership and operation. This total cost incorporates all other factors, such as capacity, labor, fuel, tractor size and the initial cost of the equipment. The total cost includes the cost of ownership, which is primarily depreciation of equipment and interest paid on money invested in the equipment. Operating costs—machinery repair, maintenance, fuel and labor—are also included, along with miscellaneous costs, such as twine.

Total costs vary widely because they are affected by farm size and age of equipment. Typical cost figures are given in Table 1 for comparison purposes. These cost figures should be considered only as a guide—your costs may vary considerably, depending on your particular conditions. The cost figures given were developed by analyzing all machines for the same two farm sizes—a small farm producing 150 tons of hay per year and a larger farm producing 400 tons per year. All equipment was considered to be purchased new and owned 10 years.

Some difference in cost exists among mower-conditioners. Flail machines can be owned and operated at lower cost, but losses are higher. The value of the loss (about $2.50/ton) more than offsets any economic benefit of the lower cost machine. Rotary disk mowers are more expensive, particularly on smaller farms. The higher initial cost is not fully offset by increased performance.

Very little difference in costs exists among rakes. Round balers cost slightly more than rectangular balers due to the higher initial cost and the requirement of a larger tractor.

Labor costs can make handling and transporting bales from the field to storage the most expensive part of hay making. The method that requires the least labor and, therefore, costs the least is handling large round bales with an automatic wagon. If "free" labor were considered in the analysis, the comparison of hay handling systems would change considerably.

Storage costs are also given in Table 1. For inside storage, a pole barn, enclosed on three sides and with a useful life of 15 years, was considered. Total storage cost reflects depreciation and interest on money invested in the structure.

ROUND VS. RECTANGULAR BALE SYSTEMS

Totaling values for factors of individual machines enables comparison of total systems. As an example, a comparison of large round bale and small rectangular bale systems for a large farm is given in Table 2. Both systems used a cutterbar mower-conditioner, a parallel-bar rake and the appropriate baler. Rectangular bales were transported with three bale wagons and manually unloaded, and round bales were hauled with an automatic wagon. The round bale system was compared for both inside and outside storage.

Table 1.
Typical values for various requirements, performance measures and costs of hay harvesting operations used in the Midwest.

Machine	Losses (%)	Capacity (a/hr)	Labor Reqmt. (hr/ton)	Fuel Reqmt. (gal/ton)	Tractor Reqmt. (hp)	Price ($)	Total Cost[2] 150 ton/yr ($/ton)	Total Cost[2] 400 ton/yr ($/ton)
Mower (9 ft)	6	4.4	0.17	0.14	20	2,800	4.90	—
Mower-conditioners (9 ft)								
Cutterbar	8	4.0	0.18	0.27	35	10,000	11.50	6.30
Flail	11	4.4	0.17	0.35	50	7,800	10.00	5.50
Rotary disk	8	5.2	0.14	0.48	80	13,700	15.40	7.80
SP cutterbar (14 ft)	8	6.1	0.12	0.36	—	30,000	—	12.70
Rakes (9 ft)								
Parallel bar	3	4.4	0.17	0.14	20	2,800	4.90	3.20
Wheel	5	4.4	0.17	0.14	20	2,100	4.30	3.00
Rotary	10	4.4	0.17	0.14	20	2,400	4.60	3.10
Balers								
Rectangular	3	5.7	0.13	0.22	40	10,000	12.10	7.50
Round	10	6.1	0.12	0.27	55	12,000	15.00	8.40
Transport								
3 wagons w/bale thrower	0.5	6.5[1]	0.68	0.25	35 × 2	8,500	13.30	9.20
Auto. bale wagon	0.2	4.5[1]	0.24	0.42	40	14,700	17.30	11.40
Round bale mover	0.1	2.0[1]	0.55	1.87	80	500	15.10	—
Round bale wagon	0.1	5.0[1]	0.22	0.56	60	7,800	11.90	7.30
Storage								
Inside	5	—	—	—	—	—	5.00	5.00
Outside	15	—	—	—	—	—	0.00	0.00

[1]Capacity given in ton/hr.
[2]Total cost includes depreciation, interest, insurance, shelter, repairs, maintenance, fuel and labor for the tractor and machine used to perform each operation.

Major differences between the systems include greater losses, lower labor requirement and higher fuel requirement for the round bale system. For a round bale system, total cost is similar to that of the rectangular bale system. Reduced labor in handling offsets the costs of greater loss and higher equipment cost for the round baler. Eliminating the cost of storage cuts the total cost an additional $5 per ton of hay.

The most important comparison, however, is the net return, or the difference between the crop value and total cost. The crop has an estimated potential value of $85/ton. Crop losses, however, reduce the crop value. Subtracting the costs for harvest, storage and crop loss provides the net return.

When large round bales are stored inside, the net return is $4/ton less than that of the rectangular bale system. Outside storage of round bales reduces the farmer's return by an additional $2/ton. Structures for hay storage can be economically justified and should always be used in the Midwest to preserve hay quality.

Table 2.
A comparison of the cost and net return for harvest and storage of 400 tons of alfalfa hay per year with three harvesting systems commonly used in the Midwest.

	System 1 Rectangular Bale	System 2 Round Bale, Inside Storage	System 3 Round Bale, Outside Storage
Average loss (%)[1]	18	24	32
Labor reqmt. (worker-hr/ton)	1.2	0.7	0.7
Fuel reqmt. (gal/ton)	0.9	1.2	1.2
Total cost ($/ton)[2]	31	30	25
Value of Crop loss ($/ton)[3]	15	20	27
Net return ($/ton)[4]	39	35	33

[1]Total loss is one minus the products of one minus each individual loss.
[2]Total cost of owning and operating all harvesting equipment, including labor.
[3]Value of loss based upon a hay value of $85/ton.
[4]Net return equals potential hay value ($85/ton) minus total cost minus value of crop loss.

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CHEMICAL PRESERVATION OF FORAGES: Techniques and Economics

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A major problem in the production of quality hay has always been the time required to dry the crop in the field to a moisture content suitable for storage. Rain frequently occurs before the hay is dry, increasing loss and decreasing quality. Research data show that 20 percent of the hay crop dry matter can be lost by the time the crop is placed in storage, even in good drying conditions. Adverse drying conditions often cause 30 to 50 percent loss and, of course, very poor conditions can cause complete loss of the crop. Certain nutrient losses are often of the same order or greater than dry matter loss. Field loss is directly related to the length of time the crop is in the field and inversely related to the moisture content of the crop as it is baled. In other words, the quicker the hay is baled and the wetter the hay is when baled, the lower field losses will be.

Products that improve or maintain hay quality during storage are commonly termed preservatives. They are normally applied during the baling operation but may be applied during handling or storage. Major chemicals used as hay preservatives are propionic acid and other acid mixtures. Other materials used as hay preservatives include anhydrous ammonia, urea, sodium diacetate and bacterial inoculants.

The major benefit of any hay preservative is reduced harvesting and storage losses. Leaf loss can be excessive when alfalfa is harvested at a moisture content below 18 percent. Even at optimum moisture for baling—18 to 20 percent—losses are high as leaves shattered by the baler are dropped to the ground. Baling at a higher moisture content—25 to 28 percent—reduces the loss of high quality leaves and cuts field curing time. Special treatment is needed, however, to prevent the development of mold, which causes heating and loss of hay during storage.

Chemical preservatives work primarily as fungicides to prevent the development of fungi (molds). Sufficient acid may also inhibit bacterial growth. Bacteria added as inoculants to hay are supposed to grow and produce compounds that inhibit the growth of fungi and undesirable bacteria. The bacteria used to date produce lactic acid, but lactic acid has no antifungal activity.

Chemical preservation of forages should not be confused with a process called chemical conditioning. Chemical conditioning occurs when a chemical that speeds drying is applied to the crop as it is mowed. Different chemicals and processes are used for these two treatments, but the benefits of each individual treatment will be additive when both are used on the same crop. More information on chemical conditioning can be found in Extension bulletin E-1995, "Chemical Conditioning of Forages: Techniques and Economics."

Equipment and Procedure

Hay preservatives come in three major forms: liquid, granular and pressurized liquid. Each form requires different application equipment.

Liquid materials are generally acid mixtures. Propionic acid is recognized as the most effective acid for hay preservation. Acids sold commercially for hay preservation often include other acids or compounds blended with propionic acid. Bacterial inoculants can also be mixed with water and applied as liquids.

A spray system mounted on the baler is used to apply liquid materials. A tank with a 50 gal capacity is adequate. It can be mounted on either the baler or the tractor. Other components of the spray system include pump, line filter, pressure regulator and nozzles. Spray systems designed for this purpose can be purchased for about $800 to $1,000. You can also buy individual components to fabricate a system.

Uniform distribution of the spray material throughout the bale is important for best results with the treatment. Nozzles are normally mounted just behind or over the baler pickup for best coverage of the hay as it moves into the baler. A flooding type nozzle is often used to improve coverage and distribution.

Propionic acid should be applied to hay in proportion to the amount of moisture in the hay. When hay is in the

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moisture range of 20 to 25 percent (just about dry), about 15 lbs of acid should be applied to each ton of hay. At 25 to 30 percent moisture (slightly damp), apply a minimum of 20 lbs/ton. At 30 to 35 percent moisture, propionic acid treatment is not recommended, but if it is used, acid should be applied at a minimum of 30 lbs/ton.

Commercial chemicals available for hay preservation contain between 10 and 80 percent propionic acid. University and field research has shown that the best preservation is obtained with mixtures of 60 percent or more propionic acid. Feed-grade, 100 percent propionic acid can also be purchased from the manufacturer by the grower for use on his/her farm. Whether purchased from a supplier or directly from the manufacturer, propionic acid mixtures are normally diluted with water on a 1:1 ratio to improve coverage of the hay as they are applied.

Dry chemicals, including sodium diacetate and urea, can be applied with a granular applicator. Applicators are available from the supplier of sodium diacetate, or they can be purchased directly from a manufacturer. Granular applicators can be mounted on the baler at the entrance of the bale chamber to drop the chemicals into the hay at this point.

Uniform distribution of the chemical throughout the hay can not be accomplished with this applicator alone. A blower device developed at MSU provides for better distribution. The applicator device is mounted on the front of the baler to meter the dry chemical into the blower. Fans are used to create an air stream that carries the dry chemical through sheet-metal "nozzles" to the rear of the baler pickup, where it mixes with the hay (Fig. 1). This device is not commercially available at this time, but someone adept at working with sheet metal can build it.

The most difficult chemical to apply on the field baler is anhydrous ammonia because it must be contained under pressure to prevent vaporizing. Two devices have been developed for this purpose, but neither is commercially available at this time. These devices inject anhydrous ammonia into the bale as it is formed in the baler. The ammonia unites with moisture in the hay, where it is retained as a preservative.

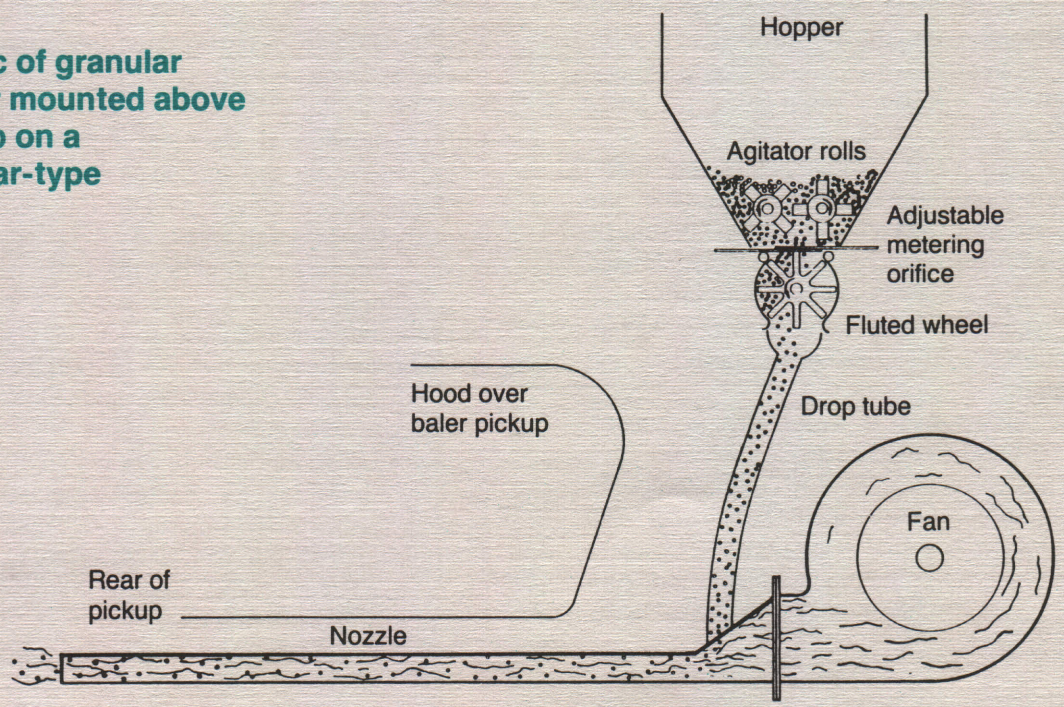
Another method of applying ammonia, developed at Purdue University, can be used during storage. Hay is baled, stacked, covered and tightly sealed in a plastic wrap. The proper amount of ammonia is slowly released from a nurse tank into a container that was previously placed near the center of the stack. The ammonia evaporates and moves through the stack under the plastic, creating an ammonia atmosphere. A good seal is required to prevent molding of the hay and to avoid ammonia loss. Hay is normally kept in the sealed stack until a week before it is fed.

Anhydrous ammonia should be applied to high moisture hay at a rate of 20 to 40 lbs/ton of hay at hay moisture contents of 25 to 35 percent, respectively. When hay has a moisture level greater than 35 percent, treatment with ammonia or any other preservative is not recommended.

What to Expect from Chemical Preservatives

University research has shown that propionic acid and anhydrous ammonia are the best of the available materials for hay preservation. Either of these materials is effective when properly used, but each has major disadvantages.

Figure 1.
Schematic of granular applicator mounted above the pickup on a rectangular-type baler.



Propionic treatment of moist hay will reduce mold development and thus reduce heating and storage loss. When treated moist hay is compared to field-dried hay, the major difference is in the reduction of field loss. Baling moist hay—21 to 25 percent moisture—may increase yield 5 to 10 percent. Most of this increase is high quality leaf material, so the quality of the hay will also be increased. Crude protein, for example, may be increased by one percentage point.

In general, moist hay treated with propionic acid will store about the same as dry hay. With the proper amount of acid, little mold should occur. Somewhat more heating will occur in the moist treated hay than in dry hay, but the heat developed is insufficient to reduce the quality of the hay. Dry matter loss during storage will be slightly higher for the treated moist material than for untreated dry hay but below that of untreated moist hay.

Treated moist hay may also be more palatable after storage. Some feeding trials with sheep have shown an increase in animal acceptance and a reduction in feeding loss when treated moist hay was compared with field-cured hay. Other feeding trials with dairy cows have shown no difference in feed intake, milk production and milk fat percentage. Treated hay, therefore, is at least as good as field-cured hay and in some cases better.

The major disadvantage of propionic acid treatment is its effect on equipment. The acid is corrosive and promotes rust, which can be very hard on the baler after a couple of years. Removing all treated hay from the baler between periods of use will help reduce rust. Washing the baler after acid use and rinsing with sodium bicarbonate will further reduce rust.

Other potential disadvantages of propionic acid treatment are color and odor. Acid-treated hay will often be brown and have an acid smell. People handling bales in poorly ventilated areas may find acid vapors annoying.

Anhydrous ammonia can be used as a preservative with results similar to those of propionic acid. In addition, the nitrogen in the ammonia will increase the crude protein content of the treated hay. Anhydrous ammonia may also be corrosive, but because it is applied in storage, corrosion of equipment is not a problem.

Anhydrous ammonia applied at a rate of 40 lbs/ton of hay is an effective preservative of alfalfa hay at moisture contents as high as 35 percent. Ammonia treatment reduces molding, heating and dry matter loss in the stored hay. Chemical analyses of treated and untreated hay at the same moisture content have shown increases in measurements of crude protein and digestibility. Our research has shown that the treatment can increase crude protein about two percentage points.

Ammonia-treated hay has been fed to dairy cows with no detrimental effect. Dry untreated and wet treated alfalfa hay fed to dairy cows produced no differences in actual and fat-corrected milk, percentages of milk constituents or dry matter intake. When used with a lower quality grass hay, the ammonia treatment increased palatability and dry matter intake but again did not affect milk production.

Ammoniation of hay was shown to be beneficial in beef production. Feeding treated orchardgrass hay to steer calves increased hay consumption by 17 percent and increased daily weight gain. Feeding treated bermudagrass to lactating beef cows also increased consumption and produced calves with heavier weaning weights.

The major disadvantage of anhydrous ammonia is its threat to human and animal safety. Strong concentrations of anhydrous ammonia vapors can cause severe burns, blindness and death. Because ammonia seeks out moisture, eyes, lungs and bare skin are most susceptible to damage. After ammonia is placed in moist hay, it unites with moisture in the hay and becomes relatively harmless. People handling ammonia-treated bales, however, may find vapors obnoxious and irritating, particularly in poorly ventilated areas.

Ammonia treatment of forages has been reported to cause toxicity to animals if not used properly. Symptoms of the toxicity are hyperexcitability, circling, convulsions and death. Newborn calves nursing cows fed ammoniated forages can be affected. The exact cause is not known, but the toxicity appears to occur as a result of the reaction between the ammonia and soluble sugars in the forage. Toxicity occurs most often when ammonia is applied to high quality forage at greater than recommended application rates. Anhydrous ammonia should be used with care. If any signs of toxicity occur, animals should be removed from the treated feed immediately.

Urea is a much less harmful and objectionable chemical than ammonia. Urea is decomposed by bacteria on the hay to form ammonia and carbon dioxide, and both of these chemicals prevent growth of fungus. Urea can be applied in a granular or powdered form or sprayed as a liquid. Repeated tests at MSU, however, have not shown any improvement of storage of high moisture alfalfa hay with granular or liquid urea treatment. Therefore, urea is not recommended as a hay preservative.

Sodium diacetate has been used with limited success as a hay preservative. Our research indicates that it should be used only when the hay is almost dry (20 to 23 percent moisture). Baling hay at this moisture level does not reduce field losses, however, so little advantage is gained.

Several inoculant products are being marketed for hay preservation. We have tested several of these products at MSU and have found no improvement in hay preservation. Other investigations have had similar results. We do not recommend inoculant products as hay preservatives.

Economics of Chemical Preservation

Propionic acid and anhydrous ammonia are the chemicals most feasible for use as preservatives for high moisture hay. The costs and average expected benefit of these two chemical treatments are given in Table 1. Conditions will vary widely. At times the treatments will be of little value, while at other times they may save the crop. This analysis simply describes what could be expected on the average if the treatments were used on all hay under all conditions.

This analysis shows that propionic acid treatment is not economical because the cost of the treatment exceeds the expected benefit gained by reducing losses. The price of the chemical will influence this estimate. The price assumed—65 cents/lb—was based on a marketed hay preservative. If the propionic acid is bought directly from a manufacturer at 45 cents/lb, the farmer will just break even.

Propionic acid should not be used on all hay. It can be used to get into the field a little earlier, but as hay dries further, the treatment can be discontinued. Other times when an acid treatment should be used are in the evening, when hay is no longer drying, or when rain is anticipated. When used only under these conditions, the treatment can be more cost effective.

An analysis for anhydrous ammonia shows this treatment to be very economical. The high economic benefit is primarily due to the increased protein obtained with the treatment. This analysis assumes that the protein provided through the nitrogen in the ammonia is as beneficial to the animal as any other protein source. (This assumption has not been proven.) Even without the protein benefit, this treatment is more cost effective than propionic acid, primarily because of the lower cost of the chemical.

The cost not considered in this analysis is the cost of safety. Anhydrous ammonia is a hazardous material. The cost of a serious accident could well offset any economic benefit obtained with the treatment. Likewise, the treatment must be assured to be safe for the animals. Losing animals could again be very costly and outweigh any benefit from the treatment.

Summary

Chemicals can be used both to speed the drying and to improve the preservation of hay. Different chemical treatments are required for the two processes, but both treatments can be applied to the same alfalfa.

For preservation of high-moisture hay, only propionic acid and anhydrous ammonia have been shown to be effective. Applying these chemicals during or immediately after baling can preserve hay up to 25 to 30 percent moisture. The major benefit is reduced leaf loss at harvest, which results in a higher quality hay. In addition, anhydrous ammonia treatment will enhance the protein content of the hay.

Propionic acid treatment costs about $15/ton of hay treated. It can be economically used only when conditions make it difficult to get hay dry.

Anhydrous ammonia treatment costs about $9/ton of hay. The added protein of the ammonia makes the treatment beneficial on essentially all hay. This assumes, however, that the added protein is beneficial to the animal, that the material can be handled safely, and that it poses no threat to animal health when it is fed.

Table 1.

Average cost/benefit of using chemical preservatives to bale high-moisture alfalfa hay.

	No treatment	Propionic acid	Anhydrous ammonia
BENEFIT			
Crop yield (lb/a)	3000	3000	3000
Harvest loss (%)	20	15	15
Harvest yield (lb/a)	2400	2550	2550
Harvest crude protein (%)	16	17	17
Storage loss (%)	5	8	5
Storage yield (lb/a)	2280	2346	2423
Storage crude protein (%)	16	17	19
Gain in feed value[1] ($/a)	—	12.50	33.56
($/ton		10.65	27.70
ADDED COST			
Equipment ($/ton)	—	1.00[2]	1.50[3]
Labor ($/ton)	—	.70	2.00
Chemical ($/ton)[4]	—	13.00	5.00
Total treatment cost ($/ton)	—	14.70	8.50
NET RETURN ($/ton)	**—**	**-4.05**	**19.20**

[1]Based upon a dry matter value of 4 cents/lb and a protein value of 29 cents/lb.

[2]Includes initial cost of added equipment depreciated over five years and used to bale 250 tons of hay per year. Does not include a cost for corrosion of baler parts.

[3]Cost of plastic cover @3 cents/ft^2.

[4]Chemical costs were assumed at 65 cents/lb for propionic acid applied at 20 lb/ton and 12.5 cents/lb for anhydrous ammonia applied at 40 lb/ton of hay.

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AG FACTS

FORAGE PRODUCTION AND USE

CHEMICAL CONDITIONING OF FORAGES: Techniques and Economics

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A major problem in producing quality hay has always been the time required to get the crop dry and off the field before a rain. Research data show that even under good drying conditions, 20 percent of the crop dry matter is usually lost by the time the crop is placed in storage. A 30 to 40 percent loss occurs under adverse drying conditions, and a complete crop loss under very poor drying conditions. Nutrient losses are often of the same order or higher than dry matter loss. Generally, loss is directly related to the length of time the crop is in the field, so reducing field curing time can reduce losses and improve hay quality.

Chemicals can be used in two ways to reduce field curing time. First, they can be applied as the crop is mowed to increase the field drying rate of the cut crop. This process is referred to as chemical conditioning. The effect of the chemical is to allow moisture to leave the plant more easily. Second, chemicals can be applied at the time of baling to preserve hay baled at a higher than normal moisture content. This process of chemical preservation is discussed in Extension Bulletin E-1994, "Chemical Preservation of Forages: Techniques and Economics."

Different chemicals and processes are used for chemical conditioning and chemical preservation. The two chemical treatments can be used in one harvesting system. Benefits of each individual treatment will be additive when both treatments are used on the same hay crop.

Chemical conditioning originated in the raisin industry. In recent years, grapes have been dipped in a chemical solution to speed drying in commercial raisin production. This idea is not new—documents from nearly 2,000 years ago report the use of a dipping process to speed grape drying.

Using chemicals to speed hay drying is new. In the late 1970s, Jeff Tullberg, an Australian, determined that the process could be used in alfalfa hay production. The idea quickly spread to the United States, where research on the effectiveness of chemical conditioning was conducted primarily at Michigan State University. Scientists of the USDA and several universities extended this research and demonstrated the feasibility of the process. Chemicals that speed drying are being sold commercially for use by alfalfa growers. These chemicals are called chemical conditioners, desiccants or drying agents.

Equipment and Procedure

The chemical found to be most effective in speeding the drying process is potassium carbonate, an alkaline salt. Another alkaline salt that speeds drying is sodium carbonate. Sodium carbonate can be purchased for one-third to one-half the cost of potassium carbonate but is generally less effective.

Potassium and/or sodium carbonates can be purchased from industrial chemical suppliers as a white, fine, granular material. For chemical conditioning, a solution is prepared by mixing ¼ lb of the material per gal of water. Research has shown that a more concentrated solution does not work better.

Commercial products sold in the United States for hay drying often contain ingredients other than the alkaline salts. These include sodium silicate, methyl esters of fatty acids, vegetable oils, animal fat and various surfactants. Tests conducted at MSU have shown that the plain potassium carbonate in water solution works as well as any other solution to improve field drying over a wide range of environmental conditions. Some other combinations have given faster drying under laboratory conditions, but they have not been consistently more effective under the variable conditions in the field. An economical mixture is a combination of potassium and sodium carbonates (⅛ lb of each/gal of water). This mixture costs less than potassium carbonate alone and is equally effective.

Chemical conditioning treatments are most effective when applied while using the mower-conditioner. A spray boom mounted ahead of the reel along with a push bar (Fig. 1) is an effective method of application. The push bar pushes the crop over and opens up the leaf canopy to allow penetration of the spray onto stems. The spray boom can also be located after the reel and ahead of the

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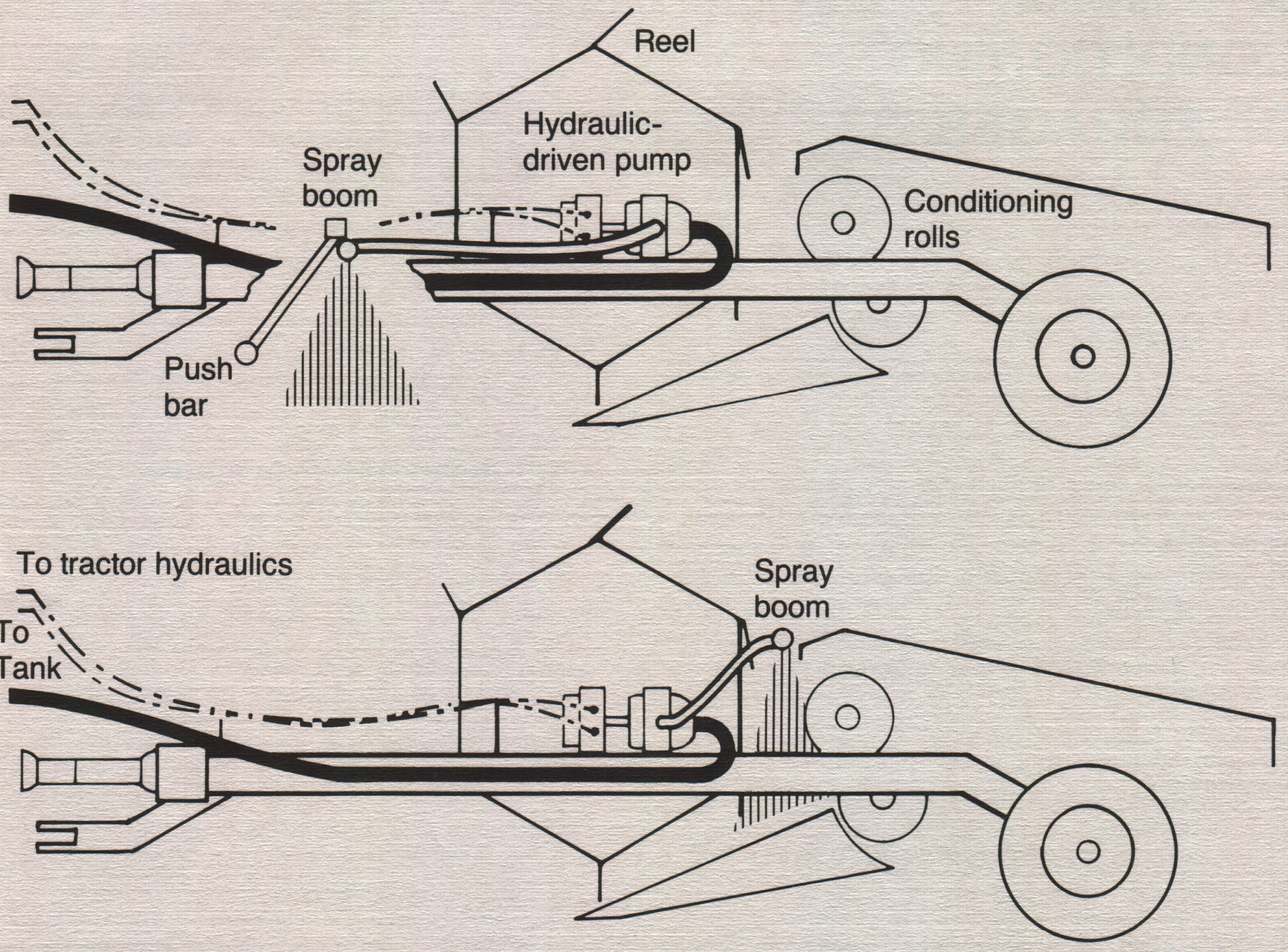
Figure 1.
Two methods for mounting equipment on a mower-conditioner for chemical conditioning of forages.



rolls on some mower-conditioners (Fig. 1). In this case, spray is applied uniformly on the ribbon or mat of mown hay just before it moves into the conditioning rolls. Either method will work, but the first method would be recommended for best results in fields with high crop yields, where better coverage may be obtained by spraying the standing crop. The tank and pump for the spray system can be mounted on the tractor or on a trailer drawn behind the mower.

With either method of application, a critical factor is the application rate. Large quantities of the solution have been required to get complete and uniform coverage of the plants. Tests conducted at MSU showed that drying speed increased as more solution was applied. Application rates as high as 100 gal/acre gave very rapid drying. Applying this much solution, however, required a large tank and the handling of unacceptably large quantities of spray solution. As a compromise, application rates of 15 to 30 gal/acre were used, with some decrease in performance. Increasing the concentration of potassium carbonate or other active ingredients in the water solution did not compensate for a decrease in application rate. High application rates have been required to obtain good coverage. Our current recommendation is a rate of 30 gal/acre in light crop yields (less than 1.5 tons/acre) and 50 gal/acre in heavier yields.

The type of nozzle used in the spray system is not critical as long as the nozzle maintains an adequate application rate. Tests have shown similar drying rates when hollow-cone, flat-fan or solid-cone nozzles are used. The operating pressure of the spray system also is not critical. A pressure of 20 to 25 pounds per square inch is satisfactory when used with nozzles designed and calibrated for that pressure.

Chemical conditioning may provide faster drying when used with some machines than with others. Tests have shown that the treatment provided faster drying when used with roll conditioners than with flail type conditioners. As the wet crop feeds into the rolls, the rolls become wet and help spread the solution over the surface of the plant for more complete and uniform coverage.

Chemical conditioning is most effective when the crop is dried in a thin mat. When possible, the shields on the mower-conditioner should be adjusted to lay the mown crop on the ground in a full-width swath. When the crop is dried in a heavier windrow, the drying rate is lower and the treatment is less effective. The chemical works by allowing moisture to leave the plant more easily. A heavy windrow inhibits moisture loss, slows the moisture removal from the plant and thus offsets the benefit of the chemical.

What to Expect from Chemical Conditioning

Chemical conditioning increases the drying rate of legumes, including alfalfa, bird's-foot trefoil and red clover. How it does this is not fully understood, but tests conducted in many areas have shown consistent increases in drying rate or reductions in drying time. The chemical is more effective on alfalfa and bird's-foot trefoil than on red clover and ineffective on brome grass and orchard grass. Grasses tend to dry faster than legumes, so a treated alfalfa and grass mixture may dry more uniformly, with both species drying at similar rates. Chemicals that speed the drying of grasses are being explored but are not available at this time.

The effectiveness of chemical conditioning of alfalfa varies among cuttings and climatic conditions. At times it provides very little benefit, but at other times conditioning may save a whole crop by avoiding a rainy period. When compared to mowing with a standard mower-conditioner alone, chemical conditioning can be expected to reduce field curing time of alfalfa in the northern United States by 0 to ½ day with first cutting alfalfa, ½ to 1 day with second cutting, ½ to 2 days with third cutting and 0 to 1 day with fourth cutting.

Several factors influence the differences across cuttings, but the primary factor is yield. Crop yield is greater with the first cutting, so less chemical is applied per unit of plant material. The heavier yields also produce heavier swaths, which inhibit drying. Limited laboratory drying data indicate that the chemical treatment is much more effective when used at warmer temperatures. Cooler temperatures during the harvest of first cutting, along with higher soil moisture content, may reduce the effectiveness of the treatment. First cutting alfalfa normally has a thicker stem, which may also impede the performance of the chemical.

The mechanism that allows moisture to leave the plant more readily also allows moisture to enter the plant more readily, so treated material tends to absorb more moisture from dew than untreated material. This additional moisture is lost rapidly from the treated material during the following morning, however.

When a rain occurs in the first day after the crop is mown, limited data indicate that the chemical tends to wash away and is not very effective. If rain occurs when the crop is nearly dry, however, treated material will redry faster than untreated material. Apparently, removing the chemical or reversing the change in the plant caused by the chemical is more difficult when the chemical remains on the plant until the plant is nearly dry. Thus, the treatment can be effective following a rain. The increase in drying rate following rain, however, is always less than that obtained in the absence of rain.

Potassium or sodium carbonate will not cause major harm to equipment. These chemicals are non-corrosive and will not promote rust. After several years of use, however, the paint on the mower-conditioner may become bleached or discolored.

When used at the recommended rates, potassium and/or sodium carbonates should not harm animals. No detrimental effects on animal health or performance have been found when hay treated with these chemicals was fed. Some research has noted slightly greater digestibility of chemically treated hay.

Economics of Chemical Conditioning

Chemical conditioning costs between $1.90 and $10/ton of hay produced, with the cost depending on the type of chemical used. Potassium carbonate costs about 45 cents/lb from industrial chemical suppliers. Properly mixed and applied at a rate of 50 gal/acre, the cost is $5.20/acre. When the hay yield is 2 tons/acre the cost is $2.60/ton. Using a mixture of potassium and sodium carbonates reduces the chemical cost to $3.80/acre or $1.90/ton. Chemical mixes developed for use on alfalfa are commercially available through some agricultural chemical suppliers at prices of 70 cents to $1.25/lb or $5 to $10/ton of hay.

The cost of additional equipment must also be considered. To equip a mower-conditioner or tractor with a tank and spray equipment costs approximately $1,000 for parts and materials. Additional labor may also be a factor. Mixing and handling the chemical may increase the time for mowing by 10 to 20 percent. An increase in mowing time increases not only labor but also the fuel requirement. Altogether, equipment, labor and fuel may cost the grower an additional 75 cents/ton of hay, for a total cost of at least $2.65/ton.

Proper evaluation of the benefit of chemical conditioning is difficult. Given long periods of good drying conditions, it gives little benefit, but under poor drying conditions it may save an entire crop. Computer simulation over 25 years of hay production has shown that chemical conditioning can reduce dry matter losses by 75 lb/acre and protein losses by 30 lb/acre in second or third cutting alfalfa. This gain in hay yield and quality can reduce a dairy farmer's use of feed supplements and cut feed costs by about $6/ton of hay fed. Comparing this savings to the treatment cost of $2.65/ton shows that the treatment provides a gain in crop value that exceeds the cost. This is not true in haylage production, however, where the modeling study showed little loss reduction and the gain in crop value was less than the cost of the treatment.

Summary

Chemicals can be used both to speed drying and to preserve hay during storage. Different chemical treatments are required for the two processes, but both treatments can be applied to the same alfalfa.

Application of a water solution of potassium carbonate to alfalfa as it is mowed will increase the drying rate of the crop. The rate of application of the chemical is important. Application rates of 30 to 50 gal/acre are required for good coverage of the plants and satisfactory drying results. The type of nozzle used to apply the chemical is not important as long as it maintains the proper application rate.

The treatment is not generally effective when used on first cutting alfalfa, but it provides good results on second and third cutting. In the later cuttings, treatment can save up to one or two days of field curing time. When rain occurs during field drying, the treatment is less effective following the rain.

The treatment costs between $2.65 and $10/ton of hay produced. The increased quality of treated hay justifies the cost in alfalfa hay production but not in haylage production.

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