Economic Potential of Preserving High-Moisture Hay

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Abstract

The economic value of preserving high-moisture hay (20-28% moisture, w.b.) was determined using a simulation model of alfalfa growth, harvest, storage, and utilization (DAFOSYM). Hay treatments of three levels of effectiveness (normal, excellent, and ideal) were evaluated for three strategies of use (limited, moderate, and heavy) on three representative farms (commercial hay, 50-cow dairy with a three-cutting hay system, and 100-cow dairy with a four-cutting hay and silage system). Simulation for 26 years of central Michigan weather gave treatment effects on average field-curing time, quantity and quality of hay produced, net returns, and breakeven treatment costs for treating small rectangular bales. A treatment of normal effectiveness (similar to propionic acid) must cost less than \$8/t DM (\$7.26/ton DM) to be profitable with limited use on any of the farms or less than \$4/t DM (\$3.63/ton DM) with moderate or heavy use. As the effectiveness of preservation increases, the breakeven cost increases to a maximum of \$21/t DM (\$19.07/ton DM) for an ideal treatment defined as eliminating all storage loss.
Keywords. Hay, Preservation, Storage.

Introduction

With annual U.S. hay production valued at over \$10 billion (USDA, 1990), reducing production losses below the typical amount of 26% (Buckmaster et al., 1990) may produce significant economic gains. Baling high-moisture hay with an effective preservative treatment may reduce rain damage and baling losses, reduce or eliminate storage losses, and maintain or improve forage quality. Losses attributed to rain damage, harvesting, and storage reduce hay value an average of \$3.10, \$4.10, and \$8.40/t DM (\$2.81, \$3.72, and \$7.63/ton DM), respectively (Buckmaster et al., 1990). This implies that using an effective treatment to preserve high-moisture hay may return up to \$15/t DM (\$13.64/ton DM), but actual economic returns have not been accurately assessed.

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Hay Preservative Treatments

Materials used to preserve high-moisture hay include propionic acid, mixtures of propionic and other organic acids, buffered acid mixtures, anhydrous ammonia, and bacterial inoculants. Propionic acid (and similar organic acids) normally reduces mold growth (Knapp et al., 1976; Khalilian et al., 1990; Rotz et al., 1991; Lacey et al., 1978). With application rates of 1 to 2% of hay weight, acid treatments can reduce heat development in high-moisture hay (Knapp et al., 1974; Khalilian et al., 1990; Lacey et al., 1978; Rotz et al., 1991; Jafri et al., 1979; Davies and Warboys, 1978; Nehrir et al., 1978). Some report similar heating in treated, damp hay and dry (< 20% moisture) hay (Jafri et al., 1979) while others report a little more heating (Rotz et al., 1991).

Propionic acid treatment reduces storage loss in damp hay during the first couple months of storage (Knapp et al., 1974; Davies and Warboys, 1978; Rotz et al., 1991; Nehrir et al., 1978), but losses are higher than those in dry hay (Rotz et al., 1991). Over six months of storage, losses are similar in treated and untreated hays at similar moisture levels (Rotz et al., 1991; Lacey et al., 1978). Dry matter lost during storage is very digestible (Buckmaster et al., 1989). Research has not shown consistent improvement in hay quality with propionic acid treatment (Davies and Warboys, 1978; Rotz et al., 1991; Khalilian et al., 1990). When compared to hay at similar moisture levels, propionic acid treatment may provide smaller decreases of *in vitro* dry matter and cell wall digestibilities (IVDMD and IVCWD; Knapp et al., 1976) and lower levels of acid detergent fiber (ADF) and acid detergent insoluble nitrogen (ADIN) (Sheaffer and Clark, 1975). When compared to dry hay, acid-treated damp hay is generally higher in fiber content and less green in color (Rotz et al., 1991).

Propionic and similar acids promote corrosion in balers and bale handling equipment. To reduce corrosion, buffered acid products have been developed. The acid is blended with ammonia or another compatible chemical to increase the pH of the treatment. Buffered mixtures can be as effective as propionic acid when equivalent amounts of propionate are applied (Lacey and Lord, 1977). One buffered product was ineffective at application rates below 0.5% (Rotz et al., 1991).

Anhydrous ammonia is perhaps the most effective hay preservative. Storage DM loss is reduced or eliminated in hay of up to 35% moisture when wrapped in plastic and treated with ammonia at 1% or more of hay weight (Knapp et al., 1975; Koegel et al., 1985; Jones et al., 1985; Atwal et al., 1986). Ammonia treatment prevents heating (Atwal et al., 1986; Weiss et al., 1982; Thorlacius and Robertson, 1984), and it may eliminate mold development while covered (Wylie and Steen, 1988; Knapp et al., 1974; Weiss et al., 1982; Atwal et al., 1986; Thorlacius and Robertson, 1984). Ammonia treatment increases crude protein (CP) content by adding nitrogen and reduces the increase in ADF and neutral detergent fiber (NDF) which normally occurs during storage (Thorlacius and Robertson, 1984). Increases in IVDMD (Kiangi and Kategile, 1981; Jones et al., 1985; Wylie and Steen, 1988; Grotheer et al., 1985; Buettner et al., 1982; Thorlacius and Robertson, 1984; Moore et al., 1981), IVCWD (Weiss et al., 1982), hemicellulose and cellulose digestion (Buettner et al., 1982; Grotheer et al., 1985; Moore et al., 1981) and energy content (Atwal et al., 1986) are reported. Ammonia treatment of forage has sometimes increased animal intake or performance (Buettner et al., 1982; Weiss et al., 1982; Moore et al., 1981), but other times it has not (Thorlacius and Robertson, 1984; Weiss et al., 1982; Jones et al., 1985).

Animal and human safety are major concerns when using anhydrous ammonia. Ammonia treatment of forage has caused toxicity to animals when not used properly (Rotz et al., 1986). Toxicity most often occurs when ammonia is used with high quality forage and at higher than recommended application rates (greater than 3% of DM). Direct exposure to anhydrous ammonia can cause severe burns, blindness, and death.

Bacterial inoculants are sometimes used to preserve high-moisture hay. Inoculation with a few forms of lactobacillus had no effect on mold, color, heating, DM loss, and quality change in high-moisture hay (Rotz et al., 1988). In another study, both lactobacillus and bacillus inoculants improved hay appearance with little effect on heating, dry matter loss, and quality compared to untreated hay of similar moisture (Tomes et al., 1990). Until a more tangible benefit is shown, the economic value of inoculant products cannot be addressed.

Objectives

To properly assess the economic value of baling and preserving high-moisture hay, the risk associated with weather effects on hay making must be considered. A model of forage production and use, DAFOSYM (Rotz et al., 1989 a), considers the timing of field operations, field drying, storage changes, and the effects of nutritive value on the economic return to the producer. DAFOSYM has proven to be an effective tool for evaluating alternative technologies and management strategies in forage production (Rotz, 1985; Rotz et al., 1989 a, 1989 b, and 1990). For this study, DAFOSYM was used to evaluate the economics of hay preservation. Specific objectives were to:

- Determine the breakeven costs of preserving high-moisture hay using hypothetical treatments with a wide range of effectiveness in reducing storage loss.
- Compare costs of current hay treatments to these breakeven costs to determine their economic value to producers.
- Determine the sensitivity of the economic analysis to major parameters or relationships used in the analysis.

Procedure

Breakeven costs for preserving high-moisture hay were determined for commercial hay and dairy farms. DAFOSYM was used to simulate the farms for 26 years using historical weather for East Lansing, Michigan. Simulations of hay baled dry (up to 20% moisture, w.b.) were compared to hay baled wet (up to 28% moisture) using partial budgeting techniques. Economic benefits of reduced loss and increased revenues from harvest and storage of high-moisture hay enabled the calculation of a breakeven cost. This cost was the maximum amount a producer could pay to treat hay without decreasing profits.

Model Description

DAFOSYM simulates the growth, harvest, storage, and utilization of alfalfa and corn crops on a dairy farm for many years of weather conditions (Rotz et al., 1989 a and 1989 b). With animal numbers set to zero, DAFOSYM simulates a commercial hay enterprise where hay price is related to the nutrient content of the hay. An economic analysis for each year compares the milk and feed sales to the costs of production. Crop losses and nutrient changes are considered during harvest, storage, and feeding. A 26-year simulation allows inclusion of risk in analyzing system performance and economics under historical weather patterns varying from poor to excellent for hay production.

When hay is baled above 20% moisture, timeliness of harvest, respiration, rain, and machine-induced losses are affected. High-moisture baling allows an earlier start in the day which provides more time for harvest. Respiration loss is a function of hay moisture content, temperature, and the length of the drying period (Buckmaster et al., 1990). Since most plant respiration ceases at moistures below 27%, baling hay at 20 to 28% moisture has little effect on plant respiration. Rain loss is an exponential function of the accumulated rainfall during field curing (Rotz et al., 1989 a). Reducing field exposure time through earlier baling at times avoids rain loss. Another benefit from baling high-moisture hay is reduced baler loss. The baler's shattering of leaves is an exponential function of hay moisture (Buckmaster et al., 1990). Simulated baler loss varies from about 6% for hay baled at 12% moisture content to 3.7% at 28% moisture (fig. 1). Baler loss is primarily highly digestible, leaf material.

A treatment is needed to prevent excessive storage loss in wet hay (>20% moisture). In DAFOSYM, the DM loss during storage is directly related to the heat generated by microbial activity in the hay. Heat generation is a function of the moisture content and density of the hay (Buckmaster et al., 1989). Dry matter lost is digestible, non-fiber material; therefore, fiber content increases and crude protein increases slightly. The acid detergent insoluble protein content of the hay is directly related to the amount of heating that occurs.

The economics of hay preservatives were determined for three strategies of use and three levels of effectiveness. The three strategies of use were defined as limited, moderate, and heavy. Under limited use, if a plot of hay was dry enough for harvest as high-moisture hay (<28% moisture), the model looked ahead to determine if rain was to occur during the remainder of that day or the next. The farmer (decision maker) was given a 60% probability of making the right decision on whether or not to bale the hay wet with a treatment. This was modeled by generating a random number between 0 and 1. If rain was to occur and the random number was less than 0.6 or if rain was not to occur and the number was greater than 0.6, the hay was baled.

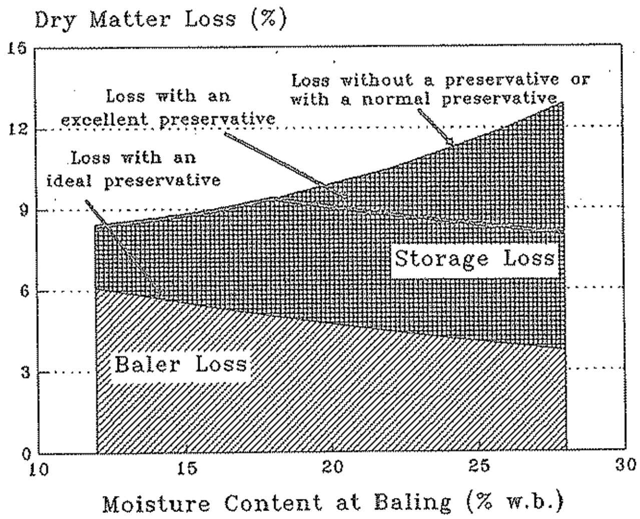

Figure 1–Average baler and storage losses predicted by DAFOSYM and the losses assumed for normal, excellent, and ideal preservation.

Otherwise, the hay was allowed to dry further. Using this strategy, limited amounts of treated hay were baled when the probability was high for avoiding rain damage. Moderate use attempted baling all hay as high-moisture hay. Some hay dried enough for stable storage without treatment (below 20% moisture, w.b.) while waiting for other plots to be baled and was not treated with a preservative. Heavy use of a preservative used the same assumptions as moderate use except that treatment was applied to all hay regardless of moisture content.

The three levels of effectiveness of hay preservatives were defined as normal, excellent, and ideal. Normal effectiveness was modeled as described earlier for preservation with propionic acid. A 60% reduction in the heating of treated hay (degree days of hay temperature rise) was assumed compared to untreated hay of similar moisture. The hay remained wet during storage where a lower level of microbial activity occurred over a longer period to give a dry matter loss equal to that in untreated hay of similar moisture. Loss of crude protein, gain in acid detergent insoluble protein, and gain in fiber concentration were modeled as functions of heating and DM loss (Buckmaster et al., 1989). Hay treated with an excellent preservative was assumed to have the same heating, DM loss, and quality changes during storage as dry hay (18% moisture). This reflects the goal of current preservatives. For an ideal preservative, all heating, loss, and quality change during storage were removed (fig. 1).

Potential returns for using each high-moisture hay strategy were determined by comparing the performance of representative farms using the strategy to the same farms with all hay baled at less than 20% moisture. The increased return for the farm was the increased income from feed and milk sales minus any change in production costs, excluding hay treatment costs. Production costs included variable costs for fertilizer, seed, chemicals, machinery, fuel, labor, storage, and appropriate capital charges (Rotz et al., 1989 a). The increased return was divided by the amount of hay treated to determine a breakeven treatment cost. The cost of the treatment must be less than the breakeven cost to realize an increase in farm profit.

Farm Descriptions

Three synthesized, representative farms were used in the evaluation. A commercial hay farm had 100 ha (247 ac) of alfalfa hay with hay sold after storage. A small dairy farm had 50 dairy cows plus replacements with 30 ha (74 ac) of corn and 30 ha (74 ac) of alfalfa harvested as hay. On a larger dairy farm, 100 cows plus replacements were fed from 50 ha (123 ac) each of alfalfa and corn. First and fourth cuttings of alfalfa were harvested as silage with second and third baled as dry hay. Crops on each farm were grown on a clay loam soil with a water holding capacity of 306 mm (12 in.). Equipment and storage structures are listed in Table 1.

The commercial hay and small dairy farms used a three-cutting alfalfa harvest system with all alfalfa baled in small, rectangular bales. Alfalfa was cut with a mower-conditioner, laid to dry in wide [1.9 m (6.2 ft)] swaths and raked prior to baling. Harvest began for the first three cuttings within five days of 2 June, 10 July, and 20 August when the CP content of the growing alfalfa dropped to 21%. The fourth cutting which could only be harvested as silage began on 15 October. Hay was stored in an enclosed structure with high-quality (less than 43% NDF) hay stacked separately from low-quality hay. Separation by quality allowed more efficient forage allocation to the dairy herd. Alfalfa silage, corn silage, and high-moisture shelled corn were stored in concrete-stave silos (Table 1).

Hay produced on the commercial hay farm was marketed after six months of storage. The price of each lot of hay was set according to the relative feed value (RFV) of the lot. Hay price was linearly related to RFV with prices from \$63 to \$114/t DM (\$57 to \$104/ton DM) for RFV from 100 to 180. RFV was estimated with relationships given by Linn and Martin (1989). To fit their relationships to DAFOSYM, ADF content of alfalfa was linearly related to NDF with data from the National Research Council (1988). Therefore, relative feed value was given by:

$$\mathrm{RFV} = 8066/\mathrm{NDF}(\%) - 49.02 \qquad (1)$$

The herds on the dairy farms included cows and replacement stock. Cows in their first lactation formed 26% of the milking herd. Replacement stock on the small farm consisted of 15 heifers greater than one year old and 18 calves. For the larger farm these numbers were 30 and 36, respectively. Average annual milk production was set at 8000 L (18,200 lb at 3.5% fat) per cow. This production level could always be met with the forage quality available, so quality improvement did not provide more milk (Rotz et al., 1989 b).

Prices were set to reflect long-term relative values for the various farm inputs and outputs in 1990 dollars (Tables 1 and 2). A real interest rate (approximately nominal rate minus inflation) of 6% annually was used for investments. Machines and structures were depreciated over 10 and 20 years to a salvage value of 10% and 0% of their initial value, respectively.

TABLE 1. Major machines and structures used on the representative farms for crop harvest and storage

Machine or Storage Type	100 ha (247 ac) Hay Farm Size	No.	Price ($)	60 ha (148 ac) 50-Cow Farm Size	No.	Price ($)	100 ha (247 ac) 100-Cow Farm Size	No.	Price ($)
Tractors	65 kW (87 hp)	1	29,250	65 kW (87 hp)	1	29,250	80 kW (108 hp)	1	36,000
	---	-	---	50 kW (67 hp)	1	22,500	50 kW (67 hp)	1	22,500
	35 kW (47 hp), used	2	2,000	35 kW (47 hp), used	1	2,000	35 kW (47 hp), used	2	2,000
Mower-conditioner	3.7 m (12 ft) SP	1	29,700	2.7 m (9 ft)	1	9,500	3.7 m (12 ft)	1	13,200
Rake	5.4 m (18 ft)	1	7,100	2.7 m (9 ft)	1	3,150	5.4 m (18 ft)	1	7,100
Baler	large	1	13,950	small	1	10,170	medium	1	12,200
Bale wagons	4.5 t (5 ton)	3	1,900	4.5 t (5 ton)	2	1,900	4.5 t (5 ton)	3	1,900
Bale elevator	---	1	3,600	---	1	3,600	---	1	3,600
Forage harvester	---	-	---	small	1	11,920	medium	1	16,700
Forage blower	---	-	---	30 t / h (33 ton / h)	1	3,150	30 t / h (33 (ton / h)	1	3,150
Forage wagons	---	-	---	9 t (10 ton)	2	7,200	9 t (10 ton)	3	7,200
Corn planter	---	-	---	4 row	1	9,000	4 row	1	9,000
Combine	---	-	---	small, used	1	8,000	small, used	1	8,000
Hay storage	600 t (660 ton) DM	1	34,000	250 t (275 ton) DM	1	14,000	300 t (330 ton) DM	1	17,000
Alfalfa silo	---	-	---	---	-	---	117 t (129 ton) DM	2	23,000
Corn silage silo	---	-	---	117 t (129 ton) DM	1	23,000	180 t (198 ton) DM	1	30,000
HM corn silo	---	-	---	116 t (128 ton) DM	1	15,500	164 t (180 ton) DM	1	17,500

Representative Farm Analysis

The economic benefit of high-moisture hay preservation on a commercial hay farm comes from selling more hay of higher quality. On the dairy farms, more hay and a reduced requirement for corn and soybean meal lead to higher net returns. Table 3 provides a breakdown of the hay and other feeds produced, production costs, and returns for two of the representative farms.

TABLE 2. Economic parameters and prices assumed for various system inputs and outputs in the representative farm analysis

Parameter	Price
Labor wage rate	$8.50 / h
Diesel fuel price	$0.28 / L ($1.06 / gal)
Electricity price	$0.08 / kW-h
Corn drying cost	$1.10 / pt / t ($1.00 / pt / ton)
Milk price	$0.28 / L ($12.30 / cwt)
Annual cost of fertilizer, seeds and chemicals	
- new alfalfa production	$284 / ha ($115 / ac)
- established alfalfa	$136 / ha (55 / ac)
- silage corn production	$267 / ha (108 / ac)
- corn grain production	$205 / ha ($83 / ac)
Selling price of feeds	
- corn grain	$110 / t ($100 / ton) DM
- high moisture corn	$88 / t ($80 / ton) DM
- alfalfa hay*	$80 / t ($73 / ton) DM
- corn silage	$66 / t ($60 / ton) DM
Buying price of feeds	
- soybean meal	$250 / t ($227 / ton) DM
- corn grain	$117 / t ($106 / ton) DM
- alfalfa hay	$90 / t ($82 / ton) DM
Economic life and salvage value	
- economic life of machinery	10 yr
- salvage value of machinery	10%
- economic life of storage structure	20 yr
- salvage value of structures	0%
Real interest rate	6.0% / yr

* On the commercial hay farm, hay price was linearly related to forage quality with this average price.

Field-curing times were similar on the three farms (Table 4). With conventional dry hay systems, average field-curing time was about 2.8 days for high-quality hay and about 5 days for low-quality hay. The longer drying period for low-quality hay occurred largely because rain damage reduced quality and lengthened curing time. With limited baling of high-moisture hay, the average field-curing time of high-quality hay was reduced only slightly but the curing time of low-quality hay was reduced up to half a day (Table 4). Considering that more hay was harvested as high-quality when moist hay was baled, the curing time averaged for all hay was reduced more than one-half day with limited use of a preservative. When more hay was baled as high-moisture hay (moderate or heavy use), the average curing time was reduced by another one-half day.

The relative amounts of high- and low-quality hays produced were different for the three farms, but the quality of hay produced as high- or low-quality hays were similar. Less of the hay on the commercial hay farm was high-quality due to a constraint from the assumed harvest equipment which was used near its limit in harvest capacity. On the small dairy farm, the harvest system provided a more timely harvest and, thus, more high-quality hay. The quality characteristics of the hay designated as high- or low-quality varied across the different harvest strategies due to differences in the losses and quality changes during storage.

Normal Preservation

Normal preservation was represented by the treatment of high-moisture hay with a preservative such as propionic acid where heating and mold growth were reduced but DM loss and quality change during storage were the same as untreated high-moisture hay. The best approach for using this type of treatment was limited use when rain was likely. With this approach the breakeven cost for applying the treatment was about $7/t DM ($6.35/ton DM, Table 4). Under moderate use where more high-moisture hay was baled, the breakeven cost was about $3/t DM ($2.72/ton DM) on the dairy farms (Table 4). Since storage loss was not reduced with this treatment, there was an economic advantage to baling dry hay when possible. Otherwise, the

TABLE 3. Effects of baling high-moisture hay with different levels of preservation on feed production, utilization and costs for two types of farms near East Lansing, Michigan

		Commercial Hay Farm*			Dairy Farm (50 Cows)*		
Annual Production or Cost	Unit	A† (dry hay)	B (lim, norm)	C (mod, exc)	A (dry hay)	B (lim, norm)	C (mod, exc)
Preharvest alfalfa production	tDM‡	1078	1086	1096	334	335	335
High-quality alfalfa hay production	tDM	255	344	385	108	138	159
Low-quality alfalfa hay production	tDM	588	530	519	134	113	100
Corn silage production	tDM	—	—	—	95	95	95
High moisture corn production	tDM	—	—	—	78	78	78
Corn grain production	tDM	—	—	—	36	36	36
Corn grain sold (purchased)	tDM	—	—	—	32	37	38
Alfalfa hay sold (purchased)	tDM	—	—	—	17	19	21
Soybean meal purchased	tDM	—	—	—	19	18	14
Field machinery cost	$	15,661	15,769	15,710	21,888	21,908	21,867
Energy cost	$	1,651	1,681	1,666	1,189	1,194	1,183
Feed storage cost	$	4,036	4,036	4,036	4,664	4,664	4,664
Labor cost	$	8,303	8,594	8,675	7,871	8,020	8,058
Seed, fertilizer, and chemical cost	$	17,300	17,300	17,300	11,890	11,890	11,890
Corn drying cost	$	—	—	—	665	665	665
Feed purchases minus excess feed sales	$	—	—	—	269	(766)	(2222)
Production (feed) cost, excluding land	$	46,951	47,379	47,386	48,436	47,575	46,105
Income from feed (milk) sales	$	63,863	67,351	71,660	111,993	111,993	111,993
Net return above production (feed) cost	$	16,912	19,972	24,274	63,557	64,418	65,888
Feed cost as portion of milk income	%	—	—	—	43.2	43.8	43.7
Breakeven cost of treatment	$/tDM	—	7.49	9.68	—	7.50	10.77

* The commercial hay farm has 100 ha (247 ac) of alfalfa and the dairy farm has 30 ha (74 ac) of alfalfa, 30 ha (74 ac) of corn. Both farms harvest three-cuttings as small, rectangular bales of alfalfa hay which are stored inside.

† (A) conventional dry hay harvest, (B) limited baling of high-moisture hay with a treatment of normal effectiveness, and (C) hay baled between 20 and 28% moisture was treated with preservative of excellent effectiveness.

‡ Tons equal 1.1 times tonne (t).

increased storage loss in wet hay offsets the reduction in field loss obtained by baling wetter hay. Only a very low cost treatment could be justified with this scenario. Application to all hay was even less economical since the treatment had no benefit on dry hay (Table 4).

Excellent Preservation

With excellent preservation, storage loss was reduced to that of dry hay. With less loss, the quantity of hay produced increased slightly (Table 4). The NDF concentration decreased since the eliminated loss was non-fiber material. There was little effect on the concentration of CP. Limited use of an excellent preservative had a breakeven cost of about $13/t DM ($11.80/ton DM) on the commercial hay farm and up to $15/t DM ($13.60/ton DM) on the dairy farms (Table 4). With moderate use, the breakeven cost was $10 to 11/t DM ($9.08 to 9.98/ton DM) on all farms. The higher breakeven cost under limited use again implied that field-cured hay was more economical when good weather was assured. With heavy use, the additional treatment of dry hay reduced the breakeven cost by up to $2.50/t DM ($2.26/ton DM) compared to that of moderate use.

Ideal Preservation

Ideal preservation eliminated storage loss. Since this loss was non-fiber material, eliminating the loss reduced the NDF concentration 2 or 3 percentage units (Table 4). Considering the shifts in the amounts of high- and low-quality hay, ideal preservation provided an NDF reduction of up to 4 percentage units when averaged over all hay. This treatment provided the greatest return when hay was sold at a price based upon relative feed value after storage.

Baling high-moisture hay with heavy treatment use provided a breakeven cost of $16/t DM ($14.53/ton DM) for commercial hay and about $12/t DM ($10.89/ton DM) for dairy farms. This implies that the storage loss and quality change in high-moisture hay had a little less value to these dairy herds than when the hay was sold priced according to RFV. With limited use, the breakeven cost was as high as $21/t DM ($19.06/ton DM). Moderate use lowered the breakeven costs about $3/t DM ($2.72/ton DM). Although storage loss was eliminated in the dry hay treated by this strategy, the breakeven cost still decreased up to $2.50/t DM ($2.26/ton DM) when all hay was treated. Storage loss in dry hay was about 5% of DM and up to 10% in high-moisture hay. The lower marginal benefit of treating the additional, drier hay decreased the average breakeven cost.

Economics of Effective Preservatives

The cost of applying propionic and similar acid products varies with price and application rate. Total cost includes application equipment, added labor for mixing and handling, and the chemical itself. Application equipment sells for $400 to $800 and when depreciated over an expected life of five years, the cost is small [$0.40 to $0.60/t DM ($0.36 to

TABLE 4. Effects of several methods of hay preservation on field-curing time, hay production and characteristics for three representative farms using historical, East Lansing, Michigan weather

		High-Quality Hay (< 43% NDF)				Low-Quality Hay (> 43% NDF)					
Application Strategy	Preservative Effectiveness	Time (days)	Amount (t DM)*	CP (%)	NDF (%)	Time (days)	Amount (t DM)	CP (%)	NDF (%)	Portion Treated (%)	Breakeven Cost ($ / t DM)
Three-cutting commercial hay farm											
none		2.7	255	20.6	42.8	5.1	588	17.8	51.4	0	—
limited	normal	2.6	344	20.9	43.2	4.7	530	18.4	51.2	44	7.49
limited	excellent	2.6	349	20.8	42.7	4.7	537	18.3	50.5	44	12.75
limited	ideal	2.6	356	20.5	41.8	4.7	547	18.1	49.6	44	21.21
moderate	normal	2.2	374	21.1	44.1	4.1	508	18.8	51.1	80	4.14
moderate	excellent	2.2	385	20.7	42.9	4.1	519	18.6	50.0	80	9.68
moderate	ideal	2.2	401	20.2	41.2	4.1	536	18.2	48.4	80	18.45
heavy	normal	2.2	374	21.1	44.1	4.1	508	18.8	51.1	100	3.36
heavy	excellent	2.2	385	20.7	42.9	4.1	519	18.6	50.0	100	7.72
heavy	ideal	2.2	403	20.2	41.0	4.1	542	18.1	47.9	100	15.89
Three-cutting hay / dairy farm											
none		2.7	108	20.6	42.8	5.1	134	18.5	50.3	0	—
limited	normal	2.5	138	21.0	43.1	4.8	113	19.2	50.2	42	7.50
limited	excellent	2.5	140	20.8	42.5	4.8	115	19.0	49.7	42	15.30
limited	ideal	2.5	142	20.6	41.7	4.8	116	18.8	48.8	42	16.71
moderate	normal	2.3	155	21.2	43.8	4.2	98	19.5	50.5	76	3.07
moderate	excellent	2.3	159	20.8	42.7	4.2	100	19.2	49.5	76	10.77
moderate	ideal	2.3	165	20.4	41.1	4.2	103	18.9	48.1	76	13.81
heavy	normal	2.3	155	21.2	43.8	4.2	98	19.5	50.5	100	2.26
heavy	excellent	2.3	159	20.8	42.7	4.2	100	19.2	49.5	100	8.12
heavy	ideal	2.3	166	20.3	40.8	4.2	104	18.7	47.4	100	11.69
Four-cutting hay and silage / dairy farm											
none		2.8	111	20.3	43.2	4.7	144	18.2	50.3	0	—
limited	normal	2.6	153	20.8	43.4	4.5	110	18.8	50.7	51	6.20
limited	excellent	2.6	155	20.6	42.6	4.6	112	18.7	50.0	51	14.60
limited	ideal	2.6	159	20.3	41.6	4.6	114	18.4	49.0	51	16.67
moderate	normal	2.3	166	21.0	44.0	4.1	98	19.1	51.2	85	2.46
moderate	excellent	2.3	171	20.7	42.7	4.1	100	18.9	50.0	85	10.74
moderate	ideal	2.3	178	20.1	41.0	4.1	104	18.5	48.3	85	14.20
heavy	normal	2.3	166	21.0	44.0	4.1	98	19.1	51.2	100	2.04
heavy	excellent	2.3	171	20.7	42.7	4.1	100	18.9	50.0	100	9.11
heavy	ideal	2.3	179	20.1	40.8	4.1	105	18.4	47.9	100	12.93

* Tons equal 1.1 times tonnes (t) and $ / ton equal 0.91 times $ / t.

$0.54/ton DM) of treated hay]. Added labor for applying the treatment is also small, about $0.10 to $0.40/t DM ($0.09 to $0.36/ton DM). The chemical, however, is a major cost with prices ranging from $1.50 to $2.00/kg ($0.68 to $0.91/lb). Assuming an application rate of 1% of hay weight (24% moisture, w.b.) gives a chemical cost of $19 to $26/t DM ($17.25 to 23.61/ton DM). Combined with equipment and labor costs, the total cost is about $20 to $27/t DM ($18.16 to 24.52/ton DM). This treatment cost is more than double the breakeven costs determined for normal preservation (fig. 2). Even if the treatment was an excellent preservative, it could not be justified on any of the three representative farms.

Buffered acid products are priced higher at $1.80 to $2.50/kg ($0.82 to $1.14/lb). Lower application rates (0.5 to 1.0% of hay weight) are normally recommended by manufacturers to keep the cost down, but their effectiveness at these low rates has not been demonstrated (Rotz et al., 1991). Nevertheless, the chemical cost at the low rate (0.5%) is $12 to $16/t DM ($10.89 to $14.53/ton DM). Including equipment and labor, the total cost is $13 to $17/t DM ($11.80 to $15.44/ton DM). Again, these costs cannot be justified for a treatment of normal or excellent effectiveness.

Anhydrous ammonia provides the best economic value in hay preservation (fig. 2), if the problem of animal toxicity can be solved. With the potential of near elimination of storage loss and possible enhancement of forage quality, anhydrous ammonia comes as close to the ideal preservative treatment as any substance at this time. Anhydrous ammonia costs about $0.26/kg ($0.12/lb). At recommended application rates (1.5 to 2% of hay weight), the chemical cost is $5 to $7/t DM ($4.54 to $6.36/ton DM). The cost of equipment, plastic, and labor to enclose the hay stack is another $4/t DM ($3.60/ton DM) to give a total cost of $9 to $12/t DM ($8.17 to $10.90/ton DM). Given that the performance is between excellent and ideal preservation, the treatment return will probably exceed the breakeven cost for any strategy of use on dairy farms. Because ammoniated hay must be maintained in a plastic wrap to enhance preservation, the treatment may not be well suited for commercial hay farms.

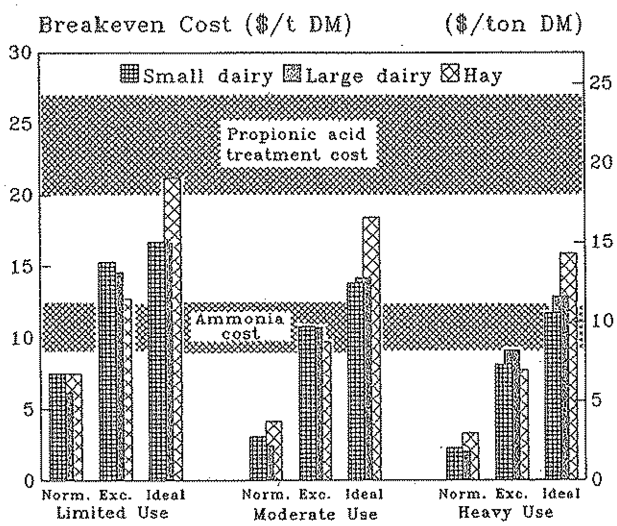

Figure 2–A comparison of the breakeven costs for different preservation treatments to current costs of propionic acid and ammonia treatments of high-moisture hay.

Sensitivity Analysis

Further analysis determined the sensitivity of the representative farm analyses to changes in model parameters. This analysis indicates how treatment performance is affected when used under slightly different scenarios. In certain cases, it can also indicate how the analysis is affected if errors were made in the original assumptions.

The previous analyses illustrated that the breakeven cost of high-moisture hay treatment was very sensitive to the harvest strategy. Another possible strategy was to bale high-moisture hay only when earlier baling was certain (100% probability) to avoid rain damage. This analysis assumed perfect knowledge of future weather; therefore, it must be viewed as a hypothetical, perfect strategy. With this strategy, 20 to 24% of the hay was baled at a high-moisture level. The breakeven cost for a treatment of normal effectiveness was $19/t DM ($17.24/ton DM) on the hay farm and $24/t DM ($21.79/ton DM) on the dairy farm. Breakeven costs were high for this scenario because the rain damage avoided greatly reduces crop value. Since the farmer has less than perfect knowledge of the weather, actual breakeven costs must be less. Breakeven costs with 50 to 100% probability of avoiding rain damage are discussed further by Borton and Rotz (1992).

The sensitivity of the analysis to several major parameters (Table 5) was determined by simulating the representative farms with and without a preservative treatment under changed parameters. The results were compared to the performance difference determined under the original simulations. To reduce the number of simulation runs, only the commercial hay and large dairy farms were used and only a treatment of normal effectiveness with limited use was analyzed.

With the standard analysis, baling began when the hay dried to less than 28% moisture. With this assumption, the average moisture content of high-moisture hay was about 24%. Hay may be baled at moistures higher than 28%, even though it is not recommended with current preservation methods. To test sensitivity, maximum baling moisture was increased to 33%. This change increased the effect of high-moisture hay baling on field-curing time by up to 43%. This gave more hay at a higher quality and a greater portion of the hay was baled with the treatment. Because normal preservation allows greater storage loss in wetter hay, this increased loss caused a substantial decrease in the breakeven cost.

When high-moisture hay preservation was combined with chemical conditioning of alfalfa, baling of high-moisture hay gave less reduction in field-curing time. Hay of slightly higher quality was obtained, and slightly less hay was treated for preservation. These factors led to little change in the breakeven cost on the hay farm and a small increase on the dairy farm (Table 5).

On dairy farms, milk production level may affect the breakeven cost of high-moisture hay treatments of normal effectiveness. In the original analysis, forage quality was always adequate to provide enough feed intake to deliver the set milk production. With a higher production goal, forage quality can limit animal intake and thus limit milk production (Rotz et al., 1989 b). Under this scenario, the breakeven cost was negative because the storage loss in high-moisture hay was of greater value to the animal than the field loss saved. Storage loss was highly digestible energy; therefore, more energy supplementation was required. Fiber concentration also increased which decreased intake potential. These changes led to a little less milk at a slightly greater feed cost which reduced the breakeven cost.

Prices in this analysis were based on long-term, relative prices over many years rather than current market prices. A relative increase in alfalfa price only affected breakeven costs on the commercial hay farm because little hay was sold from the dairy farms. A 10% increase in the average selling price increased the breakeven cost by 11%. On the dairy farms where hay was transferred to the dairy enterprise, increasing the milk price by 10% had no effect on breakeven price because the amount of milk produced was independent of the hay treatment.

The ability to predict weather (or reduce risk) obviously affects the economics of high-moisture hay systems. This ability was modeled by allowing the model to look two days into the future before mowing. Mowing was considered only when at least two sequential rain-free days occurred. The original constraint was one day. With better knowledge of the weather, high-moisture hay harvest had less effect on field-curing time. On the hay farm, slightly less hay was produced with high-moisture hay harvest under this scenario which led to a decrease in the breakeven cost. An opposite effect was found on the dairy farm where more hay was produced at a higher breakeven cost (Table 5). The difference between the two farm types was due to a constraint from harvest system capacity. Because the harvest system on the commercial hay farm was used near maximum capacity, the delay in mowing slowed harvest which offset the benefit obtained through better weather. On the dairy farm, where harvest system capacity was better matched to farm size, more benefit was obtained by waiting for better weather.

A criticism of this representative farm analysis may be that harvest losses were set too low. Overall, baler loss had surprisingly little effect on the performance and economic

TABLE 5. Sensitivity of the measures of performance and breakeven cost of hay preservation to changes in selected farm parameters

		Compared to Performance Under Original Simulations Percent increase in preservative's effect on					
			Hay Produced				
Change in the Representative Farm Parameter	Farm Type	Curing Time (%)	Amount (%)	CP (%)	NDF (%)	Portion Treated (%)	Breakeven Cost (%)
Increase of baling moisture to 33%	hay	43	1	54	−39	31	−30
	dairy	37	21	42	−27	31	−64
Include chemical conditioning*	hay	−27	−2	11	−36	−2	−1
	dairy	−65	6	−24	−37	−9	13
Increase herdmilk production level†	dairy	0	0	0	0	0	−176
Increase alfalfa selling price 10%	hay	0	0	0	0	0	11
Improve weather forecast‡	hay	−39	−2	−11	−52	6	−24
	dairy	−25	47	−11	−6	0	25
Increase baler loss 30%	hay	−2	5	8	14	0	5
	dairy	−1	4	2	4	0	5
Increase storage loss 30%	hay	0	−13	9	−31	0	−27
	dairy	0	−17	42	−34	0	−16

Note: High-moisture hay was baled only when the probability of avoiding rain damage was high (limited use). High-moisture hay was treated with a preservative of normal effectiveness.

* Hay harvest systems included chemical conditioning (use of a drying agent) as descrived by Rotz (1985).

† Potential milk production was increased to a level where feed intake and milk production are limited by forage quality (1000 L / cow / yr)

‡ At least two rain free days were required before alfalfa was mowed. For the standard comparison only the mowing day was required to be rain free.

potential of high-moisture hay harvest. A 30% increase in baler loss (for both wet and dry hay) provided only a 5% improvement in the breakeven cost of the treatment (Table 5).

Storage loss had more impact than baler loss on the performance and economic value of the process. An increase in storage loss caused a substantial decrease in the preservative's effect on the quantity of hay produced, an increase in its effect on hay quality, and a decrease in breakeven cost (Table 5).

In summary, the economic potential of high-moisture hay harvest and preservation was very sensitive to the milk production potential of the dairy herd and somewhat sensitive to the moisture content at which baling commences. Assuming a higher milk production potential or higher moistures at baling both led to a decrease in breakeven costs. The representative farm analyses were designed to study high-moisture hay harvest and storage under the best scenarios. It is unlikely that realistic changes in model parameters can provide large increases in the breakeven costs.

The sensitivity analysis assumed a preservative with normal performance. If excellent or ideal performance were assumed, the effects of several parameters would change considerably. Increases in baling moisture, herd milk production and storage loss would have greater positive effects on breakeven costs.

Conclusions

Hay treatments with normal effectiveness (similar to propionic acid) must be applied at a total cost of less than \$8/t DM (\$7.26/ton DM) to obtain economic benefit with limited use. When treating most or all hay, the cost must be less than \$4/t DM (\$3.63/ton DM). Breakeven costs are similar for commercial hay and dairy farms as long as hay is stored before it is sold.

Hay treatments with excellent effectiveness (losses in treated high-moisture hay are similar to dry hay storage losses) have a breakeven cost of about \$9/t DM (\$8.17/ton DM) when used on most hay and up to \$15/t DM (\$13.62/ton DM) for limited use to reduce the probability of rain damage.

Hay treatments with ideal effectiveness (eliminate all storage loss) provide breakeven costs of \$11 to \$16/t DM (\$9.99 to \$14.53/ton DM) when applied to all hay. When the treatment is used on less of the hay, the cost can be as high as \$21/t DM (\$19.07/ton DM) and still result in a net economic gain.

Most current preservatives are not economically viable. The effectiveness of treatments must be increased considerably and/or the cost must be substantially reduced to provide economic benefit to the producer.

A sensitivity analysis illustrates that the breakeven costs of a preservative of normal effectiveness cannot be greatly improved through realistic changes in the assumed parameters of the analysis.

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