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Evaluator for Round Hay Bale Storage

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Round bales are a common method of handling and storage forages, yet many producers fail to use appropriate storage. The objectives of this work were to develop a decision framework and spreadsheet implementation of the framework useful for analysis of the many round bale storage options: outside storage, in-barn storage, group covering, individual stretch wrapping of bales, and manual bagging of bales. Costs due to added machinery, added labor, a structure, site preparation and maintenance, and bale covering were assessed and compared with the benefits from not storing hay outside. Generally, some protection from weather is profitable, but determination of the most profitable alternative requires an individualized analysis. A breakeven analysis showed that there are few situations where the net gain from building an open-sided barn is less than zero; however, in-barn storage may not always be the best option.

LARGE ROUND hay bales are very popular. North American sales statistics indicate that 16 000 to 18 000 round balers are being sold each year; this compares with only 5000 to 6000 rectangular balers. An issue of utmost importance with respect to round bales is their storage. Despite many studies which indicate the magnitude and quality of losses incurred with outside storage of round bales, most round bales are still stored outside, uncovered, and on the ground—many times along a fence. This is rarely the most profitable storage option and, despite many attempts to get this point across, it has not been made clear to the general farming population.

Generalized statements such as "group covering of round bales is best," or "building of a hay storage barn is only economical where more than 15 in. of rainfall occur during the storage season" could certainly make decisions much easier. The difficulty is that such generalizations are not possible. The value lost during outside storage varies with location, time of storage, and value of the hay being stored. Furthermore, the benefits of a storage alternative are just as variable. The data summarized in Table 1 indicates this variability.

A limited amount of previous work has focused on economics of hay storage alternatives. Lechtenberg and Petritz (Hoard's Dairyman, 1982) determined the amount of storage loss during outside storage needed to justify a barn. Buckingham (Hoard's Dairyman, 1990) also compared barn cost to loss value. These popular press articles, and other similar ones, left out some key factors for such an analysis, such as costs of added labor and added machinery. They also did not provide for describing a producer's specific situation to determine the outcome. There are also alternatives to outside hay storage besides building a dedicated hay storage barn (e.g., plastic bags; Laflamme, 1989).

Heslop and Bilanski (1986) evaluated outside storage, in-barn storage, and individual bale wrapping with plastic. They determined that the cost of inside storage was

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Abbreviations: DM, dry matter; NDF, neutral detergent fiber.

Table 1. Summary of selected research indicating the variability in storage losses incurred in round hay bales.

Source	Storage dry matter loss, %
Outside storage	
Anderson et al., 1981	14
Belyea et al., 1985	15
Huhnke, 1988	13.1
Verma and Nelson, 1983	27.6, 39.8
Atwal et al., 1984	40
Baxter et al., 1986	33.5, 35
Covered storage	
Belyea et al., 1985	6
Huhnke, 1988	13.1
Verma and Nelson, 1983	12.3, 11.1, 45.3
Atwal et al., 1984	30
In-barn storage	
Anderson et al., 1981	3
Belyea et al., 1985	2
Huhnke, 1988	2
Verma and Nelson, 1983	2.3, 8.8
Atwal et al., 1984	9
Baxter et al., 1986	7.1, 13.2

equal to 14% of loss and that plastic wrapping of round bales resulted in the lowest cost of production. They included fixed and variable costs for five levels of production. This analysis was thorough for the options consdiered, but addressed only a few storage options. The analysis was also specific to one region of North America.

Objectives

In light of the need for individualized analysis of hay storage options and the number of alternatives available, the objectives of this work were to (i) develop a framework for evaluating the economics of a round bale hay storage option, (ii) implement the framework in a user-friendly spreadsheet format, and (iii) draw generalized conclusions regarding indoor, outdoor covered, and outdoor uncovered hay storage.

DECISION FRAMEWORK

A decision regarding a hay storage alternative involves a comparison of the benefits and costs. Evaluation of a storage alternative should consider all costs incurred with the alternative. Those of major interest include costs of added machinery, added labor, a structure, site preparation and maintenance, and bale covering material. These can be expressed in many different terms such as initial cost of equipment or a structure ($), annualized cost or benefit ($/yr), and cost or benefit per unit stored ($/ton—i.e., cost per unit placed into storage, not removed from storage). The framework outlined here expresses fixed costs, variable costs, and benefits on an annualized basis ($/yr). When annual benefits exceed annual variable costs while covering annualized fixed costs, the option is profitable. The net annual gain is computed as:

$$AG = AV_a - AC_f - AC_v \quad [1]$$

where:

AG = annual net gain from the storage option, $/yr

AV_a = annual value of the loss avoided by the use of the storage option, $/yr

AC = annual costs associated with a storage option, $/yr

subscript f indicates fixed

subscript v indicates variable

The fixed and variable costs are computed as follows, with more detail in subsequent section:

$$AC_f = AC_{b,f} + AC_{m,f} + AC_{s,f} + AC_{c,f} \quad [2]$$

$$AC_v = AC_{b,v} + AC_{m,v} + AC_{s,v} + AC_{w,v} + AC_{l,v} \quad [3]$$

where:

subscript b indicates barn

subscript m indicates added machinery

subscript s indicates site

subscript c indicates reusable covering material

subscript w indicates one time use wrapping material

subscript l indicates added labor

Benefit in Value of Avoidable Loss

All storage loss cannot be eliminated. Some dry matter (DM) loss occurs in dry hay even during inside or covered outside storage (Table 1). The gain from a storage structure or covering is not the total value of the loss, but rather, the value of the avoidable loss. Inside covered storage of hay generally results not only in more DM recovery, but also higher quality in what is recovered (i.e., more digestible nutrients). On an annualized basis, the value of the avoidable loss is:

$$AV_a = A \cdot [V_i \cdot (1 - L_i) - B_o \cdot (1 - L_o)] \quad [4]$$

where:

A = annual hay production, tons/yr

V_i = unit value of hay after inside or covered storage, $/ton

L_i = DM loss during inside storage or covered storage, fraction

V_o = unit value of hay after outside uncovered storage, $/ton

L_o = DM loss during outside uncovered storage, fraction

Hay value (V_i and V_o) could be interpreted as market value or its value in terms of nutrient availability. To reasonably estimate hay value with different storage options, the price relationship of Rotz et al. (1992) was used:

$$V = -60 + 5600/NDF \quad [5]$$

where:

V = value of the hay, $/ton

NDF = concentration of neutral detergent fiber, % of DM

(Moisture content was assumed to be 15% of deriving equation 7 from Rotz et al., 1992). Assuming all storage loss is non-NDF material, any loss that occurs also reduces the value since NDF concentration increases as a result of loss of other DM (Buckmaster et al., 1990). The storage loss affect on NDF concentration is:

$$NDF_i = NDF_h/(1 - L_i) \qquad [6]$$

$$NDF_o = NDF_h/(1 - L_o) \qquad [7]$$

where:

NDF_i = concentration of NDF after inside or covered storage, % of DM

NDF_h = concentration of NDF at harvest, % of DM

NDF_o = concentration of NDF after outside uncovered storage, % of DM

Combining Eq. [5] and [6] and rearranging, a hay value function can be derived for post storage:

$$\begin{aligned} V_i &= -60 + 5600/NDF_i \\ &= -60 + 5600/[NDF_h/(1 - L_i)] \\ &= -60 + 5600 \cdot (1 - L_i)/[5600/(V_h + 60)] \\ &= -60 + (V_h + 60) \cdot (1 - L_i) \\ V_i &= V_h \cdot (1 - L_i) - 60 \cdot L_i \qquad [8] \end{aligned}$$

where:

V_h = hay value at harvest (placement into storage), \$/ton

This relationship predicts the reduction in value (reflective of quality reduction) which accompanies DM loss. A similar relationship holds for outside storage:

$$V_o = V_h \cdot (1 - L_o) - 60 \cdot L_o \qquad [9]$$

Although some outside storage loss is not on the surface of the bale, many times it is useful to visualize the loss in terms of spoilage depth on the bale. This is difficult to do as most times the spoilage is deeper on the bottom and shallower on the sides than the top surface. Nevertheless, neglecting loss on bale ends, the loss during outside storage can be approximated with a volumetric formula (Fig. 1):

$$L_o = 1 - \frac{\pi \cdot 1 \cdot (D - 2s/12)^2/4}{\pi \cdot 1 \cdot D^2/4}$$

$$= 1 - \frac{(D - s/6)^2}{D^2} \qquad [10]$$

where:

D = large round bale diameter, ft

s = average spoilage depth, in.

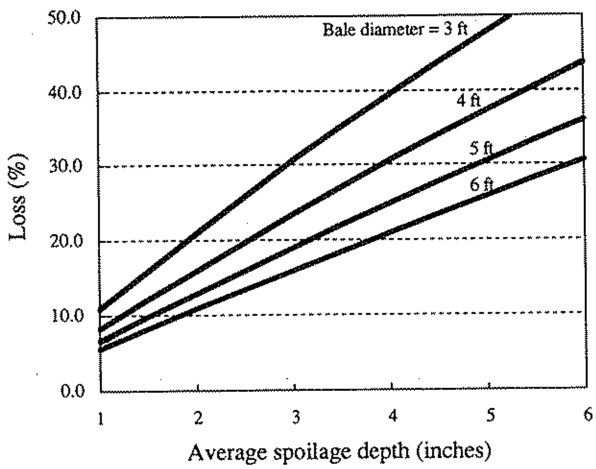

Fig. 1. Dry matter loss vs. average spoilage depth in round bales of various diameters (volumetric formula).

Costs of Added Machinery and Labor

Regardless of the storage method, some machine and labor costs are incurred. For evaluation of alternative storage methods, only the difference in these costs should be used. For example, when comparing outside storage with barn storage, only the added labor and machine needs necessitated by the use of a barn should be considered. For some alternatives, the difference in machine and labor needs will be negligible; however, for those which have significant differences, an analysis using the framework outlined here is necessary.

Machine fixed costs are the annualized equivalent of the initial price less any salvage value, determined using time value of money formulas:

$$AC_{m,f} = (P_m - SV_m)/PVIFA(i,k_m) \qquad [11]$$

where:

P_m = purchase price of the added machinery, \$

SVm = salvage value of the added machinery, current yr \$

$= P_m \cdot sv_m/(1 + i)^{k_m}$ [12]

sv_m = salvage value as a fraction of purchase price, decimal

PVIFA(i,k) = present value interest factor for an annuity

$= [1 - (1 + i)^{-k}]/i$ [13]

i = annual interest/discount rate, decimal

k_m = machine life for amortization purposes, yr

Variable costs associated with the added machinery include fuel, a proration of tractor costs and repair and maintenance costs. ASAE (1992) includes estimates of repair and maintenance functions for field machinery, but does not include such values for hay handling machinery; therefore a constant percentage of purchase price is used to reflect the cost of upkeep which is relatively small.

$$AC_{m,v} = (H_m/60) \cdot (2000 \cdot A/W) \cdot (q_f \cdot p_f + p_t) + r_m P_m \qquad [14]$$

where:

H_m = added machinery usage, min/bale

Table 2. General inputs for example analyses of hay storage options.

Abbreviation	Description	Value	Units
D	bale diameter	5	ft
l	bale length	5	ft
W	average bale weight	1000	lb
L_o	loss during outside storage	20	%
V_h	hay value at harvest (into storage)	80	$/ton
A	annual hay production	200	tons
t	days between first and last harvest	110	d
i	interest/discount rate	9	%
p_f	price of fuel	1.15	$/gal
p_t	pro-rated tractor fixed costs	6.00	$/h
p_l	price of labor	6.00	$/h

W = average bale weight, lb
q_f = fuel consumption rage, gal/h
p_f = price of fuel, $/gal
p_t = pro-rated tractor costs, $/h
r_m = repair and maintenance costs for hay handling machinery, fraction of initial cost per year

Added labor requirements (placement into storage, covering, removal from storage, etc.) for a storage treatment or structure usually can be estimated in terms of labor needs per bale of hay handled. Using a unit price of labor (p_l), the annual labor cost is:

$$AC_{l,v} = p_l \cdot (H_l/60) \cdot (2000 \cdot A/W) \qquad [15]$$

where:
P_l = price of labor, $/h
H_l = added labor needed for the alternative storage method, min/bale

Costs of a Dedicated Hay Storage Barn

For sizing a hay storage barn, the number and size of the bales to be stored are needed. With inputs of hay land area, annual yield, average bale weight, and the maximum portion of annual production in the barn at any given time, the number of bales for which capacity is needed is:

$$n = 2000 \cdot A \cdot f/W \qquad [16]$$

where:
n = number of bales to be stored at one time
f = fraction of average annual production to be stored at one time

If the hay is fed (or sold) at a uniform rate throughout the year, the maximum fraction of annual production to be in the barn at any one time is related to the time between first harvest and last harvest. Recognizing that feeding may not be at a uniform rate or that yields may be more or less than average, the fraction of the average year's production to be stored at one time can be estimated by:

$$f = (1 - t/365) \cdot SF \qquad [17]$$

where:
t = time period between the first and last hay harvest, d
SF = safety factor for barn sizing

Table 3. Inputs and results for an example analysis of in-barn hay storage.

Abbreviation	Description	Value	Units
L_i	unavoidable loss	4	%
h	average stack height	3.0	bales
p_b	unit price of barn	7.50	$/sq ft
k_b	barn life for amortization purposes	10	yr
g_b	barn taxes and insurance	1	% init. cost/yr
r_b	barn repair and maintenance	1	% init. cost/yr
P_m	price of added machinery	1200	$
sv_m	salvage value of added machinery	0	% init. cost
k_m	machinery life for amortization purposes	5	yr
H_m	added machienry time	10	min/bale
r_m	machinery repairs and maintenance	2	% init. cost/yr
q_f	fuel consumption rate	2.50	gal/h
H_l	added labor	10	min/bale
AG	annual net gain from in-barn storage	1580	$/yr
	net gain from in-barn storage	7.90	$/ton

The safety factor accounts for differences in feed rate throughout the year as well as yield deviation from average.

If the size of the bales is known in terms of diameter (D) and length (l), the volume (v), density (D), and required space for storage can be determined as:

$$v = \pi \cdot D^2 \cdot l/4 \qquad [18]$$

$$d = W/V \qquad [19]$$

$$S_v = 4/(\pi \cdot l) = 1.27/l \qquad [20]$$

$$S_h = 4/(\pi \cdot D) = 1.27/D \qquad [21]$$

where:
v = volume, cu ft
D = bale diameter, ft
l = bale length, ft
d = bale density, lb/cu ft
S_v = stacking space needed per unit volume stored with vertical axis bale stacking, sq ft/cu ft
S_h = stacking space needed per unit volume stored with horizontal axis bale stacking, sq ft/cu ft

Many times bale diameter and length are approximately the same and stacking orientation does not have a significant affect on dimensions of the needed barn, as S_v and S_h are very similar. Required barn area can be determined as:

$$A_b = A \cdot f/c \qquad [22]$$

where:
A_b = barn area required, sq ft
c = unit capacity of the barn, tons/sq ft
= h/A_{cs} [23]
h = average height of stack over the barn/site area, number of bales
A_{cs} = cross sectional area per unit of hay stored with a stacking height of 1 bale, sq ft/ton
= $2000 \cdot S_v/d$ OR $2000 \cdot S_h/d$ [24]

The annualized cost of a barn, AC_b, must be known

Table 4. Inputs and results for an example analysis of group covering of bales.

Abbreviation	Description	Value	Units
L_i	unavoidable loss	8	%
h	average stack height	2.0	bales
p_s	unit price of site work	0.50	$/sq ft
k_s	site life for amortization purposes	10	yr
r_s	site repair and maintenance	1	% init. cost/yr
p_c	unit price of covering material	7.00	$/bale
k_c	covering material life for amortization purposes	5	yr
P_m	price of added machinery	1200	$
sv_m	salvage value of added machinery	0	% init. cost
k_m	machinery life for amortization purposes	5	yr
H_m	added machinery time	10	min/bale
r_m	machinery repairs and maintenance	2	% init. cost/yr
q_f	fuel consumption rate	2.50	gal/h
H_l	added labor	12.4	min/bale
AG	annual net gain from group covering	2130	$/yr
	net gain from group covering	10.60	$/ton

Table 5. Inputs and results for an example analysis of individual wrapping of bales.

Abbreviation	Description	Value	Units
L_i	unavoidable loss	8	%
h	average stack height	1.5	bales
p_s	unit price of site work	0.50	$/sq ft
k_s	site life for amortization purposes	10	yr
r_s	site repair and maintenance	1	%init. cost/yr
p_w	unit price of wrapping material	2.50	$/bale
P_m	price of added machinery	1600	$
sv_m	salvage value of added machinery	0	% purch. price
k_m	machinery life for amortization purposes	5	yr
H_m	added machinery time	10	min/bale
r_m	machinery repairs and maintenance	2	% init. cost/yr
q_f	fuel consumption rate	2.50	gal/h
H_l	added labor	10	min/bale
AG	annual net gain from individual wrapping	1520	$/yr
	net gain from individual wrapping	7.60	$/ton

to evaluate the benefits of indoor storage. One method of annualizing the cost of the barn is to amortize it over an appropriate number of years. Using a present value interest factor for an annuity (cost recovery factor) and a constant percentage to cover insurance and taxes, the annualized barn fixed cost is:

$$AC_{b,f} = P_b/PVIFA(i,k_b) + g_b \cdot P_b \quad [25]$$

where:

P_b = initial cost of barn, \$

$= p_b \cdot A_b$ [26]

p_b = initial unit cost of barn, \$/sq ft

k_b = barn life for amortization purposes, yr

g_b = insurance and taxes, fraction of initial cost/yr

Variable costs associated with a hay storage barn should be very small; however, one should include the costs of repairs, maintenance and utilities in the evaluation. Expressing these variable costs as a percentage of initial cost gives:

$$AC_{b,v} = r_b \cdot P_b \quad [27]$$

where:

r_b = repair, maintenance, and utility costs for barn, fraction of initial cost/yr

Generally, costs of site preparation would be included in the cost of the barn. Added labor and machine costs must be considered, however, when evaluating in-barn hay storage.

Costs of Reusable Covering of Bales

In addition to possible increases in labor and machinery, group covering of bales under a common tarp generally requires some site preparation (grading and laying of large stone) for proper storage. Evaluation of this cost requires the same procedure as evaluation of barn costs. It might be helpful to think in terms of Eq. [16] through [27] with the subscript b (barn) replaced with s (site). One would likely use S_h and an average stacking height over the site of two, since the stack typically would be triangularly shaped with a base three bales wide; if bales are stacked differently, the framework as outlined still applies.

Cost of the covering material is usually considered in terms of initial cost for covering a certain number of bales (e.g., \$420 to cover 60 bales). Assuming a useful life for the covering (k_c) and an interest rate (i), the annualized cost for the covering material (which would have an assumed salvage value of zero) would be:

$$AC_{c,f} = p_c \cdot n/PVIFA(i,k_c) \quad [28]$$

where:

p_c = price of covering material, \$/bale

k_c = covering life for amortization purposes, yr

Costs of One-time Use Covering of Bales

Unlike the cover material used for group covering of bales, the material used for wrapping or individual covering of bales generally cannot be reused. On an annual basis, the covering cost is expressed as:

$$AC_{w,v} = p_w \cdot (2000/W) \cdot A \quad [29]$$

where:

p_w = price of wrapping material, \$/bale

Costs of the site, added labor, and added machinery should be included when evaluating individual wrapping of bales.

EXAMPLE ANALYSES

The relationships described above have been implemented on a spreadsheet, which is available from the author (see availability note). To illustrate the evaluation process, a specific example is outlined here with generalized conclusions following. Tables 2 through 5 contain the inputs and summarize outputs for the example.

General Inputs

A farmer has 100 acres of forage, yielding an average of 2 tons/acre of round bale hay for the year ($A = 200$ tons/yr). (Other forage may be grazed or harvested as silage.) The round bales are 5 ft in diameter ($D = 5$), 5 ft in length ($l = 5$), and weigh 1000 lb ($W = 1000$) on the average. Outside storage typically results in 20% loss ($L_o = 0.20$) and hay value as harvested (entering storage) is \$80/ton ($V_h = 80$). The hay is fed uniformly throughout the year with the last harvest beginning 110 d after the first ($t = 110$). The long term interest rate is 9% ($i = 0.09$). The price of fuel is \$1.15/gal and labor costs \$6.00/h. Tractor costs amount to \$6.00/h.

Barn Analysis

Previous research has shown that the unavoidable loss during indoor hay storage is about 4% ($L_i = 0.04$); Buckmaster et al., 1989; Rotz and Abrams, 1988). Based on Eq. [4], [8], and [9], the saving of avoidable loss attributable to a hay barn would increase gross income by \$5970/yr. Costs lower than these benefits would indicate an economic advantage of a dedicated hay storage barn compared with outside storage, although other storage options may be even better.

For illustration, consider a hay storage barn that would allow for a stacking height of three bales on end ($h = 3$). Most hay storage barns with one or more open sides can be built for \$5 to \$10/sq ft, so a reasonable unit price for a barn (p_b) is \$7.50/sq ft. Even though the barn may last 20 yr or more, one would not generally use more than 10 yr for an economic evaluation; therefore, the barn life for amortization purposes (k_b) was set to 10 yr. Taxes and insurance were assumed to cost 1% of the initial cost per year ($g_b = 0.01$); repairs, maintenance, and utilities were set to another 1% of the initial cost each year ($r_b = 0.01$).

Use of in-barn storage may necessitate the purchase of a bale handling attachment which would allow for stacking the bales on end (which would not be necessary for outside storage). The added machinery costs should then be attributed to the barn storage alternative. Based on 1992 prices, reasonable inputs include a purchase price (P_m) of \$1200 for the attachment with a negligible salvage value ($sv_m = 0$) after 5 yr of useful life ($k_m = 5$). Assuming typical added time for transport (6 min/bale; 1/2 mile, 10 mph with 50% efficiency of time use) and stacking in the barn and removal from the barn (4 min/bale) gives a total machinery and labor time of 10 min/bale ($H_m = H_l = 10$ min/bale). Fuel demand during stacking and transport would be relatively low and was estimated to be 2.5 gal/h (25 hp demand with a typical tractor specific fuel consumption of 10 hp · h/gal). Repairs and maintenance on the attachment were assumed to be 2% of the initial cost per year.

The bales stacked on end result in a vertical stacking space requirement (S_v) of 0.254 sq ft/cu ft. With a stacking height of one bale, the cross sectional area of barn needed per unit stored (A_{cs}) is about 50 sq ft/ton. With a stacking height (h) of three bales, the unit capacity of the barn (c) is 0.060 tons/sq ft. Total barn area (A_b) needed for the year's production is 2320 sq ft as only 70% of annual production needs to be stored at any one time ($f = 0.7$; $SF = 1.0$).

With the inputs as described, the total cost of in-barn storage is \$4390/yr. The total cost gets contributions from the barn (70%), added machinery (21%), and added labor (9%). With the gain from avoidable loss of \$5970/yr, the scenario described would result in \$1580/yr more profit ($AG = 1580$) with hay stored in a barn than hay stored outside. This is equivalent to a savings of \$7.90/ton of hay stored.

Another perspective of evaluation is the payback period: the length of time needed for benefits to offset all costs. Payback period may be a good measure to use when short term economics (cash flow) are more of an issue than long term profitability. The payback period should not be the only measure, however, as it does not account for the barn's worth after the payback period—which can be very significant for a storage structure. For the in-barn storage alternative in the scenario used here, the payback period is about 5.3 yr. In other words, the fixed costs of added equipment and the barn would be fully recovered (in addition to variable costs as they occur) in about 5.3 yr.

Group Covering Analysis

Group covering of round bales reduces losses compared with outside storage, but not to the extent of in-barn storage (Belyea et al., 1985); therefore the unavoidable loss was set to 8%. Retrieving the avoidable loss (savings attributable to group covering with a reusable cover) could increase gross income by \$4340/yr. Costs lower than these benefits would indicate an advantage to group covering of the bales.

A common stacking method is a triangularly shaped stack with a base three bales wide; this results in an average stacking height of two bales and a site area requirement of 3480 sq ft. Site preparation of a storage facility may include necessary grading and laying of large (1- or 2-in.) stones to allow rainfall to escape. With an approximate cost of \$0.50/sq ft, a site life of 10 years, and a 1%/yr cost for site maintenance, the site costs \$290/yr.

Group covering of bales probably would necessitate the same type of bale handling apparatus as with in-barn storage. These added machinery costs should then be attributed to the group covering alternative. Inputs similar to the in-barn option were used: a purchase price of \$1200 for the apparatus with a negligible salvage value after 5 yr. Added time for transport, stacking, and removal was again assumed to be 10 min/bale (H_m = 10 min/bale) with an additional labor requirement of 2 h to cover and uncover each stack of 50 bales ($H_l = 10 + 2 \cdot 60/50 = 12.4$ min/bale). Fuel demand during stacking and transport was again assumed to be 2.5 gal/h. Annual repair and maintenance on the hay handling attachment were 2% of initial cost.

Group covering materials generally last several years, if proper care is taken; based on manufacturer claims of 5 to 7 yr, a life of 5 yr was used with an initial cost of \$7/bale.

With the inputs as described, the total cost of group covering storage is $2210/yr. The total cost gets contributions from the site (13%), covering material (23%), added machinery (42%), and added labor (22%). With the gain from avoidable loss of $4340/yr, the scenario described would result in $2130 more profit per year with hay stored under group covering than hay stored outside. This is equivalent to a savings of $10.60/ton of hay stored. The payback period for the group covering alternative in this example is about 1.7 yr.

Individual Wrapping Analysis

Analysis of individual wrapping of bales is similar to that of group covering with the following exceptions: (i) the covering material is not reusable, (ii) there is a different machinery and labor requirement, (iii) site area will be larger when stacking height is smaller.

Inputs for the example analysis included; an unavoidable loss of 8%, an average stacking height of 1.5 (triangularly shaped stack with a base of two bales wide), site preparation costs of $0.50/sq ft, a site life of 10 yr, and a 1%/yr maintenance charge on the site. Individual wrapping requires a specialized machine; based on 1992 model prices, a cost of $1600 was used. (Individual wrapping can also be done in other manners, one of which is to use a simple hay probe to lift the bales while hand labor is used to install bags or sleeves.) Machine life for amortization purposes was 5 yr with a zero salvage value at that time. As with other storage options, the added labor requirement and machine operation time were assumed to be 10 min/bale. Fuel demand was assumed to be 2.5 gal/h and machine repair and maintenance costs were set to 2% of initial cost per year.

With the bales stacked two high in a triangular stack, the site area required is 4650 sq ft; this results in a site cost of $380/yr. Individual wrapping material was assumed to cost $2.50/bale.

With these inputs, the total cost of individual wrapping is $2820/yr. The total cost gets contributions from the site (14%), wrapping material (35%), added machinery (37%), and added labor (14%). With the gain from avoidable loss being $4340/yr, the scenario described would result in $1520/yr more profit with hay stored with individual bale wrapping than hay stored outside. This is equivalent to a savings of $7.60/ton of hay stored. The payback period for this scenario is about 2.0 yr.

Storage Alternative Selection

For the example, each of the three alternatives resulted in higher profits than outside uncovered storage. The decision of which to choose should be based on economics as well as other factors. In this example, group covering is most profitable in the long run; however, if a barn can be used for storage of seed, fertilizer, equipment, etc., it may make more sense. If losses with group covering or individual wrapping exceed 8%, in-barn storage may appear to be the best choice. Other conditions may also suggest in-barn storage; however, if cash flow does not allow construction of a dedicated hay storage structure, group covering or individual wrapping may be a better alternative. Building a dedicated structure may also have benefits in terms of investment credits.

GENERALIZED RESULTS

Because the costs involved in group covering and individual wrapping are not dominated by one particular factor (site, labor, machine, or covering material), generalized results are largely inappropriate. This emphasizes the importance of a producer-specific analysis, which can be easily done with a spreadsheet implementation. For the in-barn alternative, however, approximately 70% of the cost involved was due to the structure itself. With the cost dominated by one particular factor, a breakeven analysis can be useful.

For any set of relevant inputs, there is a breakeven barn cost. If the breakeven barn cost for a situation were $8/sq ft, one would build a barn it if could be built for less than $8/sq ft. WIth the inputs as described in Tables 2 and 3, a breakeven analysis was performed.

Clearly the value of the barn (through reduced loss) is a function of the value of the hay to be stored. The benefit of reducing loss in high value hay is higher than that in low value hay. Fig. 2 illustrates the breakeven barn cost. To use the graph, identify the level of outside storage loss and select the appropriate curve. For an appropriate hay value as entering storage (horizontal axis), determine the breakeven barn cost (vertical axis). Using a barn built for less than the breakeven unit cost would result in higher profits than storing hay outside uncovered.

As an example, if the hay incurs 20% loss when stored outside and the hay is worth $70/ton (or more) at harvest, a barn costing about $10/sq ft or less would be advantageous. With the current economic climate, typical costs for building a hay storage barn range from about $5 to $10/sq ft. With typical outside storage losses commonly exceeding 15% and easily reaching 20%, it is hard to identify situations where building a hay storage barn is not economically wise. With a $5/sq ft barn, most

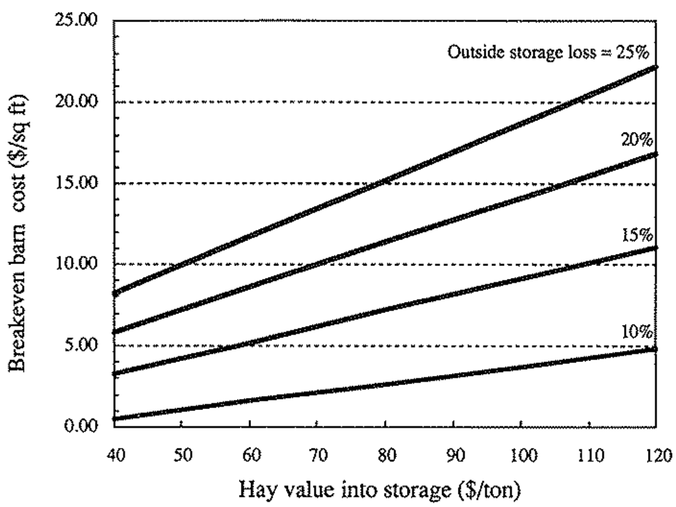

Fig. 2. Breakeven barn cost for various levels of storage loss and varying hay value at harvest. (Inputs other than storage loss and hay value are as listed in Tables 2 and 3.)

scenarios would result in a benefit from a barn, although other coverings may be even better. Exceptions are when hay value is less than \$55/ton or outside storage losses are less than 15%.

AVAILABILITY

A spreadsheet implementation is available in Lotus 123 (v 2.01 and higher) format for MS-DOS computers and Microsoft Excel (v 2.2 and higher) format for Macintosh computers. The appropriate spreadsheet software is needed. Persons desiring a copy of the spreadsheet template should send a formatted diskette (labelled with the type of format—e.g., IBM 1.44 MB or MAC 800K) along with a self-addressed, stamped diskette mailer to the author.

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