

HAY ADDITIVE REVIEW **"Where We've Been, Where We're Going"**

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INTRODUCTION/MARKET AWARENESS

The losses from harvest to feed bunk are undoubtedly greater with hay than any other crop grown by the American farmer. The economic implications of reducing losses through improved harvest technologies is staggering when one considers the 75-85 million tons of alfalfa harvested out of the total 140-145 million tons (valued at over \$10 billion) of hay produced annually in the United States (USDA, 1993).

Losses in yield and quality are primarily caused by: (1) continued plant respiration, (2) leaf shatter from harvesting equipment and (3) leaching due to rain. These dry matter losses can approximate 35-40% with a 20-60% reduction in potentially harvestable nutrients (Walgenbach et al., 1987).

The hay industry, however, is flourishing despite these incurred harvest losses, as evidenced by the USDA ranking hay as the fifth-largest U.S. crop in terms of dollar volume sold (following corn, soybeans, wheat and cotton) with estimates of the cash hay market in the 3.4 billion dollar range (WEFA, 1993). The 1991 Hay and Forage Grower Reader Profile of 489 producers showed 35% sold alfalfa hay on the cash market. Furthermore, the 1991 Hoard's Dairyman Market Study reported that 83% of the 1200 surveyed dairymen still baled hay.

Even with the current level of production, quality hay always seems to be in high demand. Respondents in the 1991 Hay and Forage Grower survey reported the average price of premium hay at nearly \$20.00 more per ton than "good" hay. Nearly 43% of these alfalfa producers reported conducting a laboratory analysis on their hay crop. Dairymen ranked forage quality fourth only to yield, stand longevity and disease resistance as important factors when purchasing alfalfa seed in a 1989 Hoard's Dairyman survey.

However apparent this emphasis for yield and quality, recently emerging hay technologies that might contribute to more efficient hay harvesting such as dessiccants, rotary disk mower/conditioners, swath inverters, tedders, improved balers, and hay additives, etc., have been adopted much slower than one might expect given the potential for economic return.

The best opportunity to reduce hay-harvesting losses is by shortening curing time. A combination of mechanical conditioning, chemical conditioning and high-moisture baling help accomplish this goal (Collins, 1988). These seem like obtainable management goals yet as an example of rate of implementation, 18% in the 1993 Hoard's Dairyman survey reported owning a tedder. Slower adoption of non-machinery technologies was observed with 3% reporting the use of chemical drying agents in the 1992 Hoard's Dairyman survey.

What about the use of hay additive technology? The 1991 Hay and Forage Grower survey showed 17.8% used a preservative or mold inhibitor on alfalfa hay (compared to 36% using an additive on silage crops) up from 13.4% in the 1989 survey. A 1985 market survey conducted by Microbial Genetics among 252 farmers in a 17 State hay producing area, indicated a 11.5% use of hay additives in 1985, although 20% reported having at least tried a hay additive in the past. The greatest adoption was among dairymen with 20% usage in 1985 while 34% reported past usage. Fed beef and cow calf operations reported a 12% and 5% usage in 1985 with some past usage reported at 19% and 13% respectively.

Respondents who had previously used additives but decided not to continue in 1985 indicated the reason as price and ineffectiveness followed by handling/application. Those who had never used a hay additive ranked handling/application and price as the major deterrents. Awareness of this available technology also seemed low with only 49% of the

respondents expressing familiarity with hay additives. A more recent Pioneer marketing survey of 722 alfalfa producers in six key dairy producing regions in the U.S. and Canada showed 12% intended to use a bacterial inoculant on hay baled in 1993.

It would appear, considering the value American hay producers place on yield and quality, that a two-fold challenge faces the U.S. hay additive industry: (1) to develop efficacious, easily applied and user-friendly products and, (2) increase awareness of the cost/benefit returns from the use of these products.

HARVEST LOSSES

No review of hay additives would be complete without a discussion of harvest and storage losses as a basis for economic justification of the industry.

(1) RESPIRATION LOSSES

Cells of cut forages are alive and functioning until the moisture content reaches about 47-48%, below which the cells die. If drying conditions are poor and the cells live a relatively long time, carbohydrates will be depleted and forage quality is diminished (Hoard's Dairyman, May 25, 1987). Under good drying conditions, respiration accounts for 2-8% loss in dry matter with losses up to 16% under poor drying conditions (Klinner and Shepperson, 1975).

Forages do not dry at a uniform rate. Kentucky research by Dougherty indicates that moisture becomes increasingly difficult to remove as the plant nears 30% moisture. A drying curve of cut forage shows that about 75% of the evaporated plant water is lost during the rapid drying phase (plant greater than 60% moisture, open stomates and low restriction to water vapor flow through the pores) and accounts for the first 20% of the drying time. The rest of the water is lost at 1/100th the initial rate over the secondary, slow drying phase (dependent largely on cuticular resistance) (Hoard's Dairyman, May 25, 1987). Common sense dictates that alfalfa cut in the late afternoon will undergo little drying through the evening hours, however, the respiration losses will continue to occur.

Wisconsin studies by Rohweder et al. (1983) have shown that it requires about 30 sunshine hours to cure non-conditioned hay in the Midwest. Effective mechanical conditioning can reduce this time by as much as two days. USDA studies by Rotz in Michigan indicate that feed value losses in hay are proportional to the length of time the crop lays in the field with up to 4% of the yield being lost each day (Roybal, 1985).

Management practices that shorten drying time resulting in reduced respiration and harvest losses include: (a) cutting early in the day to maximize solar drying, (b) cutting when anticipated weather will allow for relative humidity of the air to be below the equilibrium humidity of the forage, (c) the use

of mechanical or chemical conditioning to reduce the cuticular resistance to water escape and (d) maximizing hay exposure to wind and sunlight by creating wide and thin windrows.

(2) WEATHER LOSSES

The uncertainty of weather conditions always makes haymaking difficult. The U.S. Weather Bureau reports show that the probability of receiving three consecutive drying conditions in southern Wisconsin is less than 30% in June, less than 40% in July and less than 50% in August (Rohweder et al., 1983). These conditions are not unique to Wisconsin. The probability that hay would have 4 days to dry during May in Iowa is only 26% resulting in the majority of first crop alfalfa harvested as silage. Kentucky weather records show 7 to 9 days with more than 1/10 inch of rain occur each month between April and August (Collins, 1988).

Rain lowers the quality of hay through leaching of water-soluble carbohydrates and prolonging respiration losses. The extent of leaching loss is influenced by several factors including type of forage, stage of maturity, moisture content at the time of rainfall, amount of rainfall, frequency of rain and mowing/conditioning treatments (Bolsen, 1985). The influence of stage of maturity and amount of rain on non-equipment induced dry matter losses in alfalfa and red clover is shown in Table I. Note that leaching and respiration losses increase from only 2.0% with no rain to nearly 37% with 2.5 inches of rain. Alfalfa harvested in the bud stage undergoes more extensive leaching loss than hay harvested in full bloom presumably because the amount of soluble nutrient decrease as the alfalfa plant matures.

Table 1. The Influences of State of Maturity and Rain on Dry Matter Losses as Described in Alfalfa and Red Clover AS A Percent of Initial Dry Matter

State of Maturity and loss		Amount of Rain			
		No Rain	1 inch 1st 24 hrs	1.65 + inches	2.5 inches
Leaf Loss	Bud	7.6	13.6	16.6	17.5
	Full Bloom	6.3	9.1	16.7	19.8
Respiration & Leaching	Bud	2.0	6.6	30.1	36.9
	Full Bloom	2.7	4.7	23.5	31.8
Total Losses	Bud	9.6	20.2	46.6	54.4
	Full Bloom	9.0	13.7	40.2	51.5

Source: Rohweder et al., 1983
 * 1980 and 1981, July and August
 ** 1980
 + 1981

Leaf shatter is also increased with rain damage. Data by Collins presented in Table I indicate that leaf loss increased from 7.6% with no rain to 17.5% with 2.5 inches of rainfall. Although dry matter yields are lowered due to leaf shatter from rain damage, it should be noted that the percent crude protein in the hay might not be significantly reduced. When

forages are leached, the protein is not removed as easily from the forage as materials like sugars and various minerals. For this reason, the percentage of crude protein in moderately rain-damaged hay can actually increase. Hay buyers should not depend on protein analysis alone to judge hay quality but also include fiber analysis to more accurately determine the value of hay (Collins, 1988). Purchasing hay based on relative feed value (RFV) would help account for these elevated fiber levels.

While there is little that hay producers can do about the weather, the practice of baling at higher moistures appears to be a feasible alternative for minimizing field losses, providing the ensuing storage losses can be controlled (Von Bargaen, 1978).

(3) MECHANICAL LOSSES

Martin (1980) summarized the mechanical field losses of alfalfa to be between 8 and 45 percent. Most mechanical losses are due to "leaf shatter". Alfalfa leaves dry down 2-1/2 to 5 times faster than stems and as plant moisture decreases to below 30%, leaves become extremely brittle (Shaeffer and Clark, 1976). Leaf loss is nutritionally and economically important because alfalfa leaves comprise approximately 50% of the crop dry matter and contain over 70% of the plant protein, 65% of the digestible energy and 90% of the plant carotene (Bohstedt, 1944).

The extent of mechanical leaf loss is dependent upon crop maturity, moisture content, and rake or baler design. Walgenbach et al. (1987) developed a technique of laying down thin sheets of poly-propylene with the mower in such a way, that freshly cut alfalfa could be deposited on top of the plastic sheets. These 12-by-100 foot sheets of plastic allowed for more precise measurements of the losses incurred by subsequent raking and baling operations. These studies indicated a numerical but non-significant difference in losses from side-by-side comparisons of three types of mowers: a) rotary disk with fluted roll conditioner (5.9% DM loss), b) rotary disk with steel flail conditioner (7.3% DM loss) and c) reciprocating mower with fluted roll conditioner (3.9% DM loss). Conditioners work best when roll speed is 2-3 times faster than ground speed and tension is adjusted such that stems are cracked without the meshing or fluted rolls touching each other.

The Walgenbach study showed that nearly 50% of the total mechanical losses were incurred during mowing-conditioning and raking. This is consistent with work by Friesen (1978) which reported raking losses in alfalfa of 15-25% and from 5-10% in native grass hay. To reduce leaf shatter from raking, it is advisable not to turn or ted hay after moisture levels fall below 40 percent. Recently introduced technologies such as swath inverters also show promise for turning and narrowing the swath for baling without causing excessive leaf loss.

The final field operation also causes reduction in dry matter yields. Losses from conventional, small rectangular balers range from 3-8% while large baler losses may be as high as 15 percent (Friesen, 1978). Walgenbach et al. (1987) reported losses on three types of balers used to bale approximately 18% moisture alfalfa hay. The mean bale chamber loss of the round, fixed chamber baler with rollers was 10.9%, significantly higher than the round, variable chamber baler with belts at 3.9% or the small, rectangular baler at 2.8 percent. Several factors have been shown to increase losses in large round balers including: (a) light windrows, (b) slow travel speeds, (c) very low moisture and (d) badly weathered hay.

Reducing losses incurred by large round balers is important due to their sheer numbers. Today, large round balers outnumber square balers by two to one (Mowitz, 1988) and a 1989 survey conducted by Hay and Forage Grower magazine indicated that 49% of surveyed alfalfa producers harvested at least some large round bales. In fairness to baler manufacturers, tremendous improvements have been made in recent years ranging from improved operational speed and reliability to the use of microcomputers to control bale size and density. Round balers also exist today that allow for bale ejection on the move in addition to those that automatically steer, wrap and eject bales for improved harvest and storage efficiencies.

Arledge (1983) found that the leaf:stem ratio of alfalfa hay changed from 58:42 to 42:58 when the moisture content at baling was reduced from 25% to 15 percent. Recent studies by Wisconsin researchers (Koegel et al., 1984) have also found a negative correlation between leaf loss and bale moisture content. Walgenbach (1987) reported increased bale chamber losses, consisting mostly of leaves, when alfalfa was baled at decreasing moisture content beginning at 33% down to 14% moisture. Walgenbach noted that even with the hay baled at the higher moistures (33%), some of the leaves were already dry enough such that leaf shatter still occurred.

STORAGE LOSSES

Storage losses are directly related to microbial growth and to subsequent heating. The extent of heating depends largely on (1) the moisture of the hay, (2) the density and size of the bale, (3) the rate of bale dry-down and (4) the epiphytic microbial populations present on the hay. The biological activity in hay does not necessarily terminate at baling, especially if baling is done at higher moistures (20-30%) to reduce leaf shatter losses. Hay does not become static until it reaches about 12% moisture and the equilibrium humidity is below 65% at which time most fungi will not grow (Tomes, 1989).

If hay is baled at higher moistures and not protected by a preservative or inoculant, heating may occur. The first

temperature peak will generally occur within a few days and can be the result of aerobic bacterial growth, fungal growth and/or plant respiration. If oxygen and a favorable moisture level are available, microorganisms begin to multiply, generating heat up to 130 to 140 F. The rise in temperature tends to kill most microorganisms resulting in the gradual decline in internal bale temperatures. The initial heating in hay baled at lower moistures typically drives off moisture. However, in higher moisture bales, the hay moisture combines with water generated in the respiration process, allowing for unusually prolonged conditions that prove optimum for bacterial and fungal growth. A single, continuous temperature rise is often observed when hay is baled at higher moistures (over 30%) as a result of favorable growth conditions for selective aerobic bacteria and fungi (especially Mucorales species).

The hay may, however, undergo several heating cycles during the next few weeks as various populations of microorganisms increase and decrease. The magnitude of peak temperatures will usually be lower each time. Eventually the temperature will stabilize near ambient temperature (Prather, 1988). These secondary temperature peaks are generally the result of fungal growth. Aerobic fungi are the primary microbes responsible for the breakdown of complex carbohydrates and subsequent generation of heat (Martin, 1980). Work by Tomes (1989) also suggests that both the *Aspergillus* species of fungi and certain bacterial species are highly involved in this spoilage process. Additional research is needed in profiling the epiphytic interactions in hay for increased understanding of possible microbial manipulation of the curing process.

Heat resistant fungi and bacteria are known to be active when temperatures are between 113 and 150 F. Heating above 175 F results in the eventual death of all microbes, however, the previously generated heat can stimulate heat producing chemical reactions that further increase temperatures. Oxidation of reactive compounds may ultimately cause the temperature to rise to an ignition point of 448 to 527 F. If enough oxygen is present under these conditions, spontaneous combustion will occur resulting in fire (Martin, 1980).

The primary nutritional losses that occur during storage are due to microbial growth and the subsequent heating. Excessive heat damage can reduce protein and energy digestibility of the hay. Heat damaged protein is measured by determining the nitrogen content of the fiber in tests such as the Acid Detergent Insoluble Nitrogen (ADIN) analysis. Under normal conditions, less than 5% of the total nitrogen should be bound to the fiber fraction. It is generally felt that excessive heat damage has occurred when ADIN approaches 10% or more of the total nitrogen (Ricketts et al., 1982). Studies by Shelford (1983) showed that protein digestibility was reduced by 10% for every 5% increase in ADIN expressed as a percent of total nitrogen. Nebraska

researchers, Brandt et al. (1984), found that when the moisture content of large round bales increased from 15% to 27%, the ADIN as a percent of total nitrogen increased resulting in a decrease in protein digestibility from 71 to 53 percent. Dry matter digestibility was also reduced by 5% indicating that losses in digestible energy also occurred in the hay.

Mold growth in improperly cured hay can adversely affect palatability and feed intake, although less than 5% of the molds commonly found in hay produce any mycotoxin (Tomes, 1989). Mohanty et al. (1969) showed that feeding moldy alfalfa hay resulted in significantly lower dry matter intake, reduced weight gains and poorer feed conversion compared to feeding mold-free hay. He also reported a 25-30% decrease in the feed value of the alfalfa.

Weathering also contributes significantly to storage losses when hay is stored outside, although hay stored inside at normal moisture levels of below 20% can still experience 5-10% dry matter losses (Martin, 1980). Most weather deterioration is limited to the outside layer of the bale and at the soil surface. These losses are dependent upon: a) amount of rainfall, b) length of storage, c) storage site and d) ability of the bale to shed water. Legumes generally experience more weather losses than grass hay because they do not form as tight a weather-resistant thatch.

Purdue studies reported by Petritz (1988) indicate that hay, even when stored inside, can lose as much as 1% of the dry weight for each percentage unit of moisture loss. This loss is related to the above-mentioned metabolic activity in the hay during the final stages of drying. Hay baled at 20% moisture will likely lose 5-8% of its dry weight by the time it cures to 12% moisture. When hay is stored outside, additional dry weight loss occurs due to weather damage. The total loss, including the unavoidable 5-8% loss and that due to weathering can be as high as 40 percent.

Data reviewed by Martin (1980) suggested that losses with large round bales stored outside on the ground are about three times greater than those protected by inside storage. Furthermore, those storage losses can range from 10-42% of the original dry matter. Belyea et al. (1985) studied large round, alfalfa bale storage and feeding losses finding 40% total losses for bales stored outside with no cover, 20% losses for bales stored outside but covered and 15% for bales with inside storage. Rain penetrated 4-10 inches into the uncovered bales stored outside contributing to feeding losses up to 25% from heifers rummaging through the unpalatable hay. This Missouri study concluded that storage and feeding losses of large round bales stored outside were large enough to warrant protection of bales.

Research in Southern Indiana (Petritz, 1988) revealed that much of the weather damage is due to bale contact with the moist ground. Big round bales retained only 77% of their

original weight as unweathered hay when stored outside on the ground but was increased to nearly 86% when stored on crushed rock resulting in a 50% reduction in weather losses. Brasche and Russell (1988) found that large round bales of alfalfa-bromegrass had significantly higher concentrations of dry matter and lowered concentration of NDF and ADF when stored outside on raised tires and covered with plastic. Although this particular study found no storage treatment difference in the daily gains experienced by gestating beef cows, the researchers concluded that protective storage did offer advantages from improved dry matter recoveries.

There seems to be hay grower resistance to implementing technologies that significantly lower storage losses in large round bales. A 1989 reader survey by the Hay and Forage Grower magazine indicated that only 12% covered bales with plastic and 14% used tarps. The economics of plastic wraps or inside storage must be weighed against the value of the saved hay. Petritz (1988) reporting on storage economics, cited plastic wrap research showing that bales stored so the bottoms do not come in contact with the ground had hay quality and dry matter values similar to those with inside storage.

Labor and environmental issues also impact large bale storage technologies. A patented, easily applied, and edible alternative (Nutri-Shield, Shawnee Mission, KS.) to plastic wrap coverage of both silage and large bales was released in 1988 (Hay & Forage Grower, February, 1988). Other products designed to form a tough membrane that protects hay from weathering are currently in the developmental stages (Glick, 1989). With higher valued alfalfa hay, the economic returns from reduced losses due to inside storage can, in some cases, exceed the annual facility cost thus justifying a permanent storage structure (Petritz, 1988). A hay grower in Minnesota who sells alfalfa to a nearby racetrack developed a unique approach to storage. Hay is baled at 22-23% moisture and stored until sold in tractor-trailer vans. Vans are equipped with a pallet-like wood deck that creates an air space. A drying fan is then bolted to the underside of the trailer where a hole in the trailer floor allows for movement of air to dry the hay. The grower claims the cost of van storage is no greater per cubic foot than shed storage and the trailers can be sold if they decide to exit the hay market (Tietz, 1989).

HAY ADDITIVES

(1) DRYING AGENTS

Drying agents are the first technological advancement to hasten the field drying of forages since the advent of mechanical conditioners in the mid 1940's. Initial work with drying agents was conducted in Australia in the early 70's with research beginning in the United States near the end of the decade at Michigan State University.

The use of chemical drying agents (desiccants) consisting of potassium or sodium carbonate, sodium silicate and citric acid (aids dissolving in hard water) are applied to the stem of the alfalfa plant at the time of mowing- conditioning to help speed the drying of the stem. These naturally-occurring salts reduce drying time by acting on the moisture-conserving, waxy-cutin layer of alfalfa, clover and trefoils but are ineffective on orchardgrass, timothy or bromegrass (Rohweder et al., 1983). These chemicals are most effective when applied at 5-7 pounds of active ingredient in 30 gallons of water per acre.

Desiccants are less effective with: (a) heavy windrows that often occur at first cuttings, (b) uneven application or (c) rainy, humid conditions. Studies in Wisconsin and Minnesota have shown that desiccants are less effective in humidities over 80% and that treated hay tends to rewet faster from dew exposure, however, the desiccant treated hay also dries faster when good drying conditions reappear (Rohweder et al., 1983). Leaching losses can be greater with desiccant treated forage if hay is rained on while lying in the field.

The cost of drying agents are approximately \$1.00 per pound of active ingredient and appear to be cost effective when used to reduce the probability of rain damaged hay.

(2) ORGANIC ACIDS

Organic acids, principally propionic or propionic-acetic acid blends, have generally proven effective in preventing mold and subsequent heating in high moisture hay (Knapp et al., 1976 and Sheaffer and Clark, 1976). Their effectiveness is largely dependent upon the application rate of active ingredients and the moisture content of the hay. Recommended application rates of actual acid for small square bales generally range from .5%-1% for 20-25% moisture hay up to 1.5% acid for 31-35% moisture hay.

Walgenbach (1989) indicates that the expected results of propionic acid on hay depends upon the complex relationships between: (a) the level of inhibitory, free propionic acid, (b) the level of the non-inhibitory, ionized, propionate form of the acid, (c) the buffering capacity of the crop and (d) the hay microbial populations, some of which are capable of metabolizing the protective, free acid form.

Propionic acid products attempt to inhibit microflora growth on moist hay by striving for high levels of the inhibitory, free acid form of propionic acid (CH₃-CH₂-COOH) and lowered levels of the non-inhibitory, ionized form of the acid (CH₃-CH₂-COO⁻). Calculating dissociation constants, pKa values, gives the amount of the compound that is in the free acid form and ionized form at any given pH. For example, the pKa value for propionic acid is 4.87. At pH of 4.87, 50% of the acid exists in the inhibitory, free acid form and 50% exists in the ionized form. As pH is increased, there is a rapid logarithmic shift such that more of the acid exists in the non-inhibitory, ionized form. If the pH is lowered, the shift is

towards more of the inhibitory, free acid form. This is why propionic acid tends to work more effectively in silages with the lower pH versus on hay with a much higher pH resulting in a higher concentration of the non-inhibitory, ionized form of the acid.

Late season mold growth has been a problem sometimes associated with acid hay products. Walgenbach (1989) suggests that the mold inhibition of acid products is greatly reduced after long periods of hay storage. The acid eventually dissipates during storage while the moisture remains in the hay. This sets up ideal conditions for mold growth especially in hay removed from storage late in the feeding season.

The other reason for slow adoption of acid hay products, currently estimated at less than 10% of hay producers, is due to the pungent, vinegar-like odor and caustic nature of the products to both machinery and operator. In an attempt to overcome the objections of volatility and corrosiveness, buffered acid products that have been available in Europe for many years are now available to the U.S. hay grower. These products are buffered by the use of compounds such as ammonium hydroxide that effectively raises the pH from less than 1.0 to the more acceptable range of pH 5-6.

Buffered acid products consisting of compounds such as ammonium propionate act in a manner similar to normal propionic acid. These compounds disassociate into: a) the free acid and propionate forms, depending upon the surrounding pH, and b) ammonia based compounds that can also exhibit microflora inhibitory properties.

Limited research at both Wisconsin and Michigan suggests that buffered products perform about the same as regular acid products. Thomas (1989) conducted a 1987 laboratory scale trial in which two-100 gram samples of alfalfa were evaluated after treatment with various commercial buffered and normal acid products. The sealed samples were incubated at ambient temperature for weekly scoring of odor and visible mold growth. The results showed that the higher rates of application were more effective and that the buffered products performed equal to the normal acid products. Buffered products, although apparently equal in performance, generally cost 10-20 cents higher than normal acid products.

Data from several universities (Walgenbach, 1986) suggests that products containing a high percentage of propionic acid have successfully preserved "wet" hay when applied at rates of 1% or more of the as is weight of the hay. However, when considering the economics of applying upwards of 20 pounds per ton of hay, data suggests that propionic acid is only economical when used to reduce losses incurred from impending weather damage (Sheaffer and Martin, 1979). Grant (1989) summarized economic data from Michigan that showed the use of 25 pounds of propionic acid (\$.65/lb) resulted in a net loss over application of \$10.48/ton when

used indiscriminately on all hay. Returns were closer to break- even at \$-1.85/ton when 20 pounds of propionic acid was used selectively in adverse conditions.

Walgenbach (1987) in a study designed to evaluate the economics of 30 pounds/ton of an 80% propionic: 20% acetic acid product reported that the savings in leaf losses did not compensate for the cost of a preservative (valued at \$.65/lb) except in the study where rained-on hay had 40% total dry matter losses. Factors such as weather risk and time management are considered important when deciding to use acid preservatives. Although saving high quality dry matter such as leaves is important, Walgenbach concluded that acid preservatives might not be economical unless used to avoid rain-damaged hay.

(3) ACID SALTS

Acid salts such as sodium diacetate have also been used on high moisture hay. Sodium diacetate appears to inhibit the growth of mold by elevating the acetic acid level in baled hay. Limited published research exists on acid salts, nonetheless, Crop Cure (Domain, Inc., New Richmond, WI.), a commercial additive containing 50% sodium diacetate, was the highest-use product among readers responding to the 1989 Hay and Forage Grower magazine survey. Crop Cure fell to 12th in the 1991 survey far behind bacterial and acid products.

Rohweder et al.(1983) reported that results have been variable with sodium diacetate at the 2-3 pound/ton rate on hay greater than 23% moisture. However, Rohweder reported that these trials were with a granular product and poor distribution with low application rates may explain the variable results.

Goerke et al.(1977) reported that 3 pounds/ton of Crop Cure significantly reduced mold spore counts in small square bales of alfalfa baled at 18%, 25%, 36.8% and 38.5% moisture content. After a storage period of three months, treated hay had higher percentage protein when compared to dry controls (16.5% vs. 15.0%) and demonstrated no differences in palatability when offered in two sheep feeding trials. The product does display an EPA registration number referencing claims of mold inhibition. Johnston (1989) conducted a large round bale study in 1982 comparing 25% moisture alfalfa bales with and without Crop Cure to 18% moisture control bales. Analysis indicated no significant nutritional differences between the treated and untreated 25% moisture hay, however, both high moisture bales demonstrated higher final crude protein content. The 18% moisture, control bales were significantly higher in final percent available protein reflecting the elevated temperature and resultant heat damage that occurred in the 25% moisture bales. A subsequent sheep feeding trial did show significantly higher average daily gains for wintering, yearling ewes fed both the treated and untreated 25% moisture round bales as compared to the 18% moisture control hay.

Manufacturer recommendations for granular Crop Cure (50% sodium diacetate) are 3-4 pounds/ton for hay baled up to 20% moisture and 4-5 pounds/ton for hay baled up to 25% moisture. Cost to the hay producer is approximately \$1.00 per pound of product. Water soluble product form has been available since 1983. Application rates range from .75 to 1.25 gallons/ton with total cost similar to the granular product form (Plummer, 1989).

(4) SALT

The use of salt (NaCl) on wet hay does have a biological basis in that sufficient concentrations will absorb free water on the surface of the hay and thereby inhibit microbial growth. The problem exists in the lack of any controlled research studies, therefore, recommended rates, concentrations, palatability effects and economics lead to concern over practical limitations regarding the practice of adding salt to hay (Lacefield, 1987).

(5) ANHYDROUS AMMONIA

Anhydrous ammonia, an effective fungicide, has also been used as an additive on high moisture hay. The ammonia apparently sterilizes the hay, killing organisms that cause hay to mold. USDA researchers have effectively baled alfalfa hay at 30% moisture content with the addition of 60 pounds of ammonia per ton. However, unless covered with plastic to retain ammonia, the preserving effects of the ammonia will be only temporary (Walgenbach, 1986). Ammonia treated hay should be stored in small stacks, covered with plastic and the anhydrous permitted to equilibrate with the hay for at least three weeks (Rohweder et al., 1983). Labor and plastic costs have been problematic, however, research has been conducted at Nebraska and Purdue to develop systems to facilitate there use of the entrapping plastic and improve the ammoniating process efficiency during cold weather (Eftink, 1982).

The addition of anhydrous ammonia to low quality forages such as wheat straw or corn stalks will increase the digestibility due to the solubilization of hemicellulose and delignification (Davis, 1980). Ammonia combines with the residual moisture in hay forming ammonium hydroxide that breaks the lignin-cellulose bonds in the cell walls of the forage. It also solubilizes some of the complex carbohydrates in the plant and swells plant fiber, thereby allowing for greater rumen microbial breakdown of the forage. The improvement in digestibility will enhance dry matter intakes of low quality forages by 15 to 20% due to an improvement in the digestive rate of passage (Kuhl, 1982).

Anhydrous will also provide a source of non-protein nitrogen that may or may not be utilized by the animal depending upon nutrient demand and sources of ration protein (Sniffen and Chase, 1987).

A cost-benefit analysis of adding anhydrous ammonia limits application feasibility unless applied to low quality roughages during years of forage shortages. Total cost estimates of \$18-

20.00/ton includes \$6.00/ton for the anhydrous ammonia, \$3-4.00/ton for plastic and a conservative \$10.00/ton for labor and equipment expense.

Another drawback to hay ammoniation is the potentially dangerous volatile and caustic properties of anhydrous ammonia requiring extreme user caution. Furthermore, in addition to the potential for ammonia toxicity (Otterby et al., 1977) recent findings of Simms et al.(1984) and Weiss et al.(1984) have raised concern regarding the use of anhydrous ammonia on high quality forage crops. These researchers reported that toxic substances (presumably an imidazole or fluorescent alkaloid compound) have caused circling, convulsions and death in cattle fed the treated hay and in calves nursing cows fed the ammoniated hay. It may be advisable to refrain from ammoniating higher quality forages with high levels of ammonia (over 3% ammonia on a dry matter basis) until more research is conducted in this area.

(6) UREA

A common nitrogenous feed ingredient, urea, has been studied as an alternative to ammonia. Urea offers advantages in that it lacks the volatility, corrosiveness and potential for user injury exhibited by ammonia. Research by Ghate (1979) on hay ranging from 30-50% moisture showed no benefit when urea was applied at levels from 1.75% to 5.3% of the dry matter. Poor results are presumably due to the extreme moisture content of the hay.

Recently, Alhadhrami et al.(1989) conducted research in Arizona on early bloom alfalfa harvested at approximately 25% moisture, treated with 2% or 4% urea and fed to mid-late lactation cows. Comparisons were made against a wet (31% moisture) and dry (11% moisture) control. Results showed visually less mold on the 4% urea treated bales and lower post harvest temperatures when compared to the 2% treatment or wet control. Feed intake and milk yield in lactating cows fed the hay was not significantly different between treatments. At the end of the 4-month trial, *in vitro* neutral detergent fiber digestibilities (48 hours) were significantly higher in the urea treated hays. Caution was exercised in feeding the 4% urea treated hay by dilution of 50% of the total forage intake with normal, untreated hay. The researchers concluded that feeding 100% of the forage as the 4% treated hay probably would have produced toxic effects even though 41% of the urea nitrogen had disappeared prior to the feeding trial.

To be effective in reducing mold and browning in hay, it appears from this study that 80 pounds of urea/ton is required, costing approximately \$12.00 per ton of treated hay.

(7) FERMENTATION PRODUCTS

The American Association of Feed Control Officials (AAFCO) define fermentation products as the product derived by culturing a microorganism on appropriate nutrient media for the production of one or more of the following: enzymes, fermentation substances or other microbial

metabolites. One commercial hay product, Pro-Serve II (Conklin Company, Inc., Shakopee, MN), contains fermentation products from *Lactobacillus acidophilus* and *Lactobacillus plantarum* in combination with water, whey, molasses, lactic acid, diammonium phosphate, ammonia, yeast extract and trace minerals and nonviable *Lactobacillus acidophilus* and *Lactobacillus plantarum*. This product recommends bale moistures of less than 25% for small, rectangular bales and less than 20% for large, bales with a treatment cost of approximately \$1.50 per ton of hay. This type of hay additive should not be confused with bacterial inoculants that inoculate with living microorganisms.

Limited research exists with fermentation products or fermentation combination products. Rotz et al.(1988) did find that a nonviable lactobacillus treatment delayed bale heating during storage when compared to viable lactobacillus treatments, but there was no benefit over untreated hay at similar moisture. Deetz et al.(1989) conducted a digestion trial with lactating dairy cows comparing hay treated with a propionic acid product, Fresh Cut (Kemin Industries, Inc., Des Moines, IA) and hay treated with the fermentation/acid product, Pro-Serve II. Milk production and components were unaffected by the use of either product however, cows consuming rations containing both treatments gained more weight than cows fed the dry control hay rations. This reflects the increased in vivo digestibility of neutral detergent fiber and hemicellulose in both wet hay treatment groups when compared to the dry control hay.

(8) ANAEROBIC BACTERIAL INOCULANTS

Most microbial hay inoculants marketed today were initially developed to aid in the fermentation of silage. These products generally contain lactic acid bacteria of the genera lactobacilli, pediococci or streptococci. The effectiveness of these bacteria to work in baled hay is questionable since they are facultative anaerobes that prefer anaerobic conditions and a relatively high (greater than .95) water activity for optimal growth (Tomes, 1989).

Some researchers have reported success with specific bacterial products in arid conditions when hay was baled in the moderate range of 22-26% moisture (Brandt et al., 1984). Nelson et al.(1989) in a study of inoculated small rectangular bales found a differential effect of inoculation across the two treatment moistures of 26% and 43% with the most beneficial results in the higher moisture hay. The researchers conclude that bacterial strains and quantity of bacteria added probably need to be customized for specific bale types, baling moistures and environmental conditions.

Inoculation of large round bales baled at 26% moisture (Nelson et al., 1989) showed reduced Maillard product formation and improved digestion of dry matter and nitrogen compared to the untreated control bales. Although the inoculation prevented some high temperature-induced nutrient damage in storage, there was no evidence that altered

anaerobic fermentation was responsible for the observed beneficial effects. Costs of treatment with anaerobic bacterial products are generally in the range of \$2.00 - \$3.00 per ton of hay.

Studies by Rotz et al.(1988) and Walgenbach (Hoard's Dairyman, June 1988) showed no advantage to anaerobic bacterial inoculants when compared to untreated controls or propionic acid treated hay. These studies conducted in Michigan and Wisconsin, respectively, when compared to studies conducted in more arid regions, suggests that there may be a significant regional environment or epiphytic effect impacting the performance of anaerobic bacterial hay inoculants.

It should be emphasized that unlike chemical-based preservatives, there are tremendous biological differences between the bacterial strains contained in differing inoculant products. Negative response with one specific bacterial product should not be extrapolated to infer that all bacterial products would exhibit the same performance.

(9) AEROBIC BACTERIAL INOCULANTS

The latest entry to the hay additive market occurred in 1988 with the Microbial Genetics Division of Pioneer Hi-Bred International, Inc., introducing the first "aerobic" bacterial hay inoculant (PIONEER\ brand 1155 Alfalfa Hay Inoculant) designed specifically for alfalfa hay. This product ranked as the most used (23%) by respondents reporting the use of hay additives in the 1991 Hay and Forage Grower survey. Pioneer market data shows that over 2200 customers used Pioneer\ brand 1155 in 1993 to inoculate over 320,000 tons of alfalfa hay.

The organisms used in this product are selected strains of *Bacillus pumilus* which are spore-forming bacteria capable of growing at much lower available water levels than anaerobic silage organisms. These organisms were isolated by Pioneer microbiologists from higher moisture alfalfa hay that naturally resisted heating and mold damage. Since the organisms were adapted to alfalfa hay, they effectively compete with spoilage organisms under the aerobic conditions found in baled hay. Pioneer research data has shown this product to be effective on alfalfa hay baled in small square bales at up to 25% moisture, large round bales up to 20% and large square bales up to 18% moisture. A two-year trial at Rutgers University showed that Pioneer\ brand 1155 was effective in protecting hay baled at up to 25% moisture. The digestion trial showed that lambs fed inoculated hay gained equal to those fed dry hay and numerically outperformed the untreated high-moisture hay group in average daily gain (Emanuele, 1992). Treatment cost with this product is approximately \$3.20 per ton of hay. The innovative aspects of this technology have been recognized by the issuance of two patents by the United States Patent and Trademark Office.

FACTORS AFFECTING HAY ADDITIVE PERFORMANCE

Consideration should be given to several factors that exert influence on the efficacy of any hay additive.

(1) APPLICATION AND CALIBRATION

Applicator set-up and calibration are critical management steps in assuring that the correct amount of additive is uniformly distributed throughout the hay. Hay growers should be sure that information is provided with regards to: a) calibration, b) nozzle types, c) nozzle pressure, d) applicator positioning and e) active life of the product once put into the applicator.

(2) MOISTURE DETERMINATION

Most hay additive products suggest an upper moisture limit for which the product is recommended. This is typically in the range of 25-35% moisture. Adhering to these moisture limits is probably the most important factor in assuring satisfactory performance of the product. The problem is that moisture determination is not an easy task.

Moisture determination techniques include: (a) "twisting the windrow", (b) resistance or capacitance probe methods, (c) highly accurate, yet time consuming "cook-out" methods, (d) accurate, yet inconvenient microwave techniques, and (e) innovative, yet relatively unproven psychrometer techniques that measure relative humidity. Research is also underway to perfect baler mounted moisture sensors.

Comparative university research is needed to verify the accuracy and convenience of the available methods. Whatever method growers decide to employ, consistency is important. Growers must follow manufacturer directions and consider factors such as accurate windrow sampling and bale density. When paying for technologies such as hay additives, it seems prudent to take the time and effort to accurately determine the conditions under which the product will best perform.

(3) ENVIRONMENTAL CONDITIONS

The specific environment that hay is exposed to can affect the performance of hay additives primarily due to the profile and activity of spoilage organisms that thrive on the hay. Conditions such as rain can also alter the microflora or leach soluble carbohydrates contributing to varied product performance. Hay growers should solicit research conducted in their specific climate when considering product adoption.

(4) STORAGE AND DRYDOWN

When baling hay at higher moistures, logic dictates that the extra water must eventually migrate from the hay. Common sense must play a role when storing hay baled at higher moistures. If 1000 bales of hay are baled at 25% moisture rather than the typical 15% moisture, the removal of approximately 940 gallons of additional water will be

required during the storage period. Hay will eventually stabilize at 12-15% moisture but the time required to reach this level depends upon many factors including: a) initial bale moisture, b) relative humidity, c) air temperature, d) air movement, and e) bale density.

Rate of drydown seems to exert an effect on the pattern of microflora growth with implications as to the quality of hay exposed to long term storage. Management practices should be adopted that maximize the rate of drydown such as: a) using well ventilated storage, b) stacking alternate layers at right angles to one another, c) leaving some air space between bales, d) stacking in several small piles to increase surface area, and e) not storing field cured hay next to wetter hay treated with a hay additive product.

(5) REALISTIC PRODUCT EXPECTATIONS

Hay growers should have realistic expectations of hay additives. Additives will not be a management "cure-all". Rather, they are a value-added product designed to enhance existing management practices. Additives can also be considered a "risk management" technology, allowing growers a management option in combating weather.

There will be certain factors that growers and buyers will have to consider when using additives. Often bales will not display the "bright green" color typified by field-cured hay but rather a more "olive green" color. Growers will need to educate buyers to make purchase decisions based on laboratory analysis of the nutrient content rather than color. Producers may also have to content with factors such as loose strings due to shrink or unique stacking requirements, however, the added nutrient value coupled with the reduction in weather risk should be weighed against these minor inconveniences.

FUTURE CHALLENGES

There are several challenges and opportunities facing the hay additive industry that need addressing by qualified researchers. These challenges include:

- (1) uniformity in experimental protocols for testing of hay additives with attention to: a) application rates, b) moisture testing, c) epiphytic profiling, d) storage conditions and e) evaluation criteria.
- (2) development of quick, accurate and easily managed field methods of hay moisture determination.
- (3) hay equipment modifications to facilitate more effective and controlled application of hay additive products.
- (4) microbiological investigation of hay epiphytic interactions.

(5) hay storage and handling innovations that allow for efficient drydown with minimal labor and handling involvement.

CONCLUSION

The development of the hay additive industry can be compared to two allied products that have also witnessed tremendous change - alfalfa varieties and silage additives.

During the 1940's and 50's, plant breeders, pathologists and agronomists combined wilt resistance with winter hardiness to produce two second generation varieties called Ranger and Vernal (Rohweder, 1987). Vastly improved experimental varieties currently being released by alfalfa breeders far excel these old standards for the economically important traits of disease resistance, winter hardiness and yield.

This trend has also occurred in the silage additive industry. Once thought of as an unnecessary expense if crops were ensiled at the proper moisture; the industry has grown such that 25% of dairymen polled in the 1993 Hoard's Dairyman Market Study reported using a silage additive with bacterial inoculants comprising 74% of the total silage additive business. The reason for improved producer and university acceptance of the silage inoculants may be attributed to the fact that products marketed today are much improved compared to those sold even five years ago in terms of strain selection and product viability. Products exist today that are not only aid in the fermentation of silage but actually improve the aerobic stability and nutritive value of the forage (Soderlund, 1989).

It may not be unreasonable to predict a growth curve for hay inoculants similar to that experienced by the silage additive industry. However, one could argue that an accelerated growth curve may occur because of a greater understanding of additives due to the pioneering effort of the silage additive industry coupled with the fact that losses in hay harvesting are more readily observable than those occurring in the silo or bunker.

As forage producers are offered viable management tools through improved second and third generation products, be it alfalfa varieties, silage inoculants or hay additives, their adoption will occur if these products: (1) are easily managed, (2) improve harvest efficiency, (3) enhance the nutritional quality of the hay and (4) provide a reasonable return on investment. This points to the need for continued product testing. Hay growers and researchers should not be too hasty in permanently condemning a first generation product. Product development improvements exemplified by the less caustic nature of buffered acids or the development of aerobic inoculants, will most likely render the product increasingly effective from a performance and/or economic perspective.

Return on investment is key to the survival of any agricultural endeavor and clearly, no crop is in more dire need of efficiency improvements than that of harvesting quality hay. It will be up to university and industry researchers to develop manageable, cost effective and efficacious products and to work with progressive hay growers in developing strategies to help meet their unique management challenges.

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