Control of Losses during the Haymaking Process

Philippe Savoie, Emmanuelle Caron, and Gaëtan F. Tremblay

Agriculture and Agri-Food Canada, Soils and Crops R&D Centre,
2560 Hochelaga Boulevard, Québec, QC, Canada, G1V 2J3
Phone: 418-657-7985 ext. 5166,
E-mail: philippe.savoie@fsaa.ulaval.ca

Abstract

Haymaking is the process of converting high-moisture fresh forage into a low-moisture stable product. A large quantity of water must be evaporated, usually by natural wilting under the sun and wind. Hay is produced after several mechanical operations which include mowing, conditioning, windrow handling, and packaging into a bale or another convenient form. Hay is then placed into storage where it remains stable if the moisture content is relatively low. Mechanical losses in the field can vary from 6 to 30%. Hay storage losses are typically another 5 to 10% but can be greater if moisture is too high or forage is exposed to rain. Good management is essential to minimize field and storage losses, and preserve a high nutritive value of stored hay.

Introduction

Forage conservation systems are often defined with respect to the moisture content at harvest and storage. Direct-cut silage contains typically 70 to 80% moisture; wilted silage, 55 to 70% moisture; haylage, 45 to 55% moisture; and baleage, 25 to 55% moisture. All these systems must be sealed to ensure anaerobic conservation whereas hay storage systems are open to air movement. For this reason, hay conservation requires very low moisture content, usually below 15 to 20%, to minimize oxidative reactions and microbiological deterioration.

In several parts of the world today, silage systems are widely and successfully practiced. An important advantage of silage is the short wilting time required in the field: just a few hours when forage is stored at 70% moisture, a full day under non-rainy conditions to reach 60% moisture, a second day under sunny or windy conditions to reach about 40% moisture content. Meanwhile, hay making can require as many as four days of field drying without rain to reach the target moisture content below 20%. For this reason, hay systems have a greater risk of rain-induced and respiration losses due to prolonged wilting than silage systems.

Despite challenges with field operations, hay remains an important feed for livestock because of its recognized nutritive value. Fifty years ago, Gordon et al. (1961) observed that feed acceptance, milk production and weight gain by dairy cows were greater for alfalfa hay than silage. More recently, Petit and Tremblay (1992) noted that hay contained more undegraded protein leaving the rumen than silages; this “by-pass” protein is beneficial for lower tract digestion. Verbič et al. (1999) also estimated that hay had more metabolizable protein than direct-cut silage or wilted silage. In addition, they observed that voluntary intake by sheep was greater for hay than for silage.

Losses occur at different stages during the forage conservation. In the case of silage systems, field losses tend to be small because wilting time is short (Buckmaster et al., 1990; Savoie and Jofriet, 2003). In the case of haymaking systems, field losses tend to be high because of extended wilting, more plant cell oxidation and more mechanical treatments to accelerate drying. Overall dry matter (DM) losses during haymaking have been estimated to range between 18 and 30% (Rees, 1982; Rotz and Muck, 1994).

The present paper describes the main sources of loss during hay making. It proposes various options of field and storage management to reduce losses and conserve high quality hay.

Main sources of loss in the field

Two types of losses occur in the field: mechanical and non-mechanical (due to oxidation and leaching). Mechanical losses are usually related to one of four harvest steps: mowing, conditioning, windrow handling, and baling (McGechan, 1989). Plant species, stage of development at mowing, and timing of operations influence the amount of mechanical losses (Koegel et al., 1985a). Legumes require gentler operations than grass to minimize leaf loss (Dernedde and Honig, 1979 cited by Rees, 1982). As plants get older, they become drier and more brittle, which can contribute to increased mechanical losses (McGechan, 1989; Shinners et al., 1991).

Non-mechanical losses, sometimes called invisible losses, are due mainly to oxidation and leaching. They reduce the nutritional value of forage because the more digestible components are the first to oxidize and be leached (Rotz, 1995). They usually represent 5 to 10% of DM (Rotz and Abrams, 1988). The following sub-sections review the mechanical and non-mechanical losses in the field.

Mowing height and windrow width

Mowing height can influence harvested yield and nutritive value of forages. For example, alfalfa mowed at 10 cm above the ground over a four-year period resulted in up to 38% less yield than alfalfa mowed at 5 cm (Belesky and Fedders, 1997). Over the life-cycle of alfalfa, high mowing increased weed competition in subsequent growths and reduced alfalfa plant size more quickly than low mowing. While a low cut provides more yield, it also results in a lower quality feed. Indeed, Taylor and Rudman (1965) measured up to 15% reduction in growth rate of steers fed grass hay cut at 6.5 cm compared with grass cut at 10 cm. The cut closer to the ground contained more old growth and a higher proportion of less digestible fibre.

In Wisconsin, Wiersma and Wiederholt (2001) observed that a low mowing height of 5 cm increased alfalfa yield by as much as 25% compared to a higher 10 cm cutting height (11.0 vs. 8.8 t DM/ha). The more abundant crop had a slightly lower quality but overall dairy milk yield per unit area was 17% more (13.8 vs. 11.8 t milk/ha). More recently in New York State, Thomas (2007) also suggested that the conventional mowing height of 10 cm should be lowered to 5 cm for alfalfa-grass mixtures fed to dairy cows. He observed that the lower cut produced 13% more yield for a three-cut system than the higher cut (9.42 vs. 8.31 t DM/ha/yr). The quality was slightly lower (0.7 percentage unit less crude protein, 1.4 percentage unit more NDF). The higher quality

10-cm cut produced 3% more milk per unit forage but produced 10% less milk per unit field area. The author concluded that most farmers would prefer a 13% increase in yield at the price of a 3% loss in quality. The optimal mowing height might not be the same in all crops (grasses tend to regrow more slowly than legumes after a low cut) or environments, so local adjustments have to be validated.

When comparing hay systems using different mowers, Rees (1982) reported losses ranging between 2 and 14% (Barrington and Bruhn, 1970; Schechtner, 1977; Beckhoff et al., 1979; Dernedde and Honig 1979 cited by Rees, 1982). Rotz and Abrams (1988) reported losses for specific mowers between 1 to 3 %.

The way forage is spread on the ground after mowing will influence field drying. Rotz and Sprott (1984) observed that alfalfa left in a wide swath dried 20 to 30% faster than alfalfa left in a narrow windrow. Drying time was also reduced for alfalfa haylage in a wide swath compared to a narrow windrow (Kung et al., 2009). Grass left in a wide swath dried faster compared to grass in a narrow windrow, saving half a day of wilting time over three days when the crop was immature and under sunny conditions (Savoie et al., 1984). Another advantage with rapid drying is the preservation of nutrients such as non structural carbohydrates whose concentration remained 8% higher in fast drying swaths compared to slow drying windrows (Tremblay et al., 2011).

Conditioning and maceration

Mechanical conditioning applied at mowing or soon after can speed up the field drying process and reduce the risk of rained-on hay (George et al., 2004). Very intensive mechanical conditioning, usually referred to as maceration, will also accelerate drying but it can cause significant breakage loss when it is applied and also subsequently because the windrows are more susceptible to oxidation and leaching (Rotz et al., 1991; Savoie et al., 1993b). For example, total losses were 14.5% for macerated windrows and 3.5% for conventionally conditioned windrows after an 18-mm rainfall; they were 26.8 and 6.9%, respectively, after a 62-mm rainfall. With conventional conditioning, DM losses were reduced by increasing forward speed, or by reducing flail conditioner rotary speed (Macdonald and Clark, 1987).

Savoie et al. (1982) observed that roll conditioning and flail conditioning applied at mowing increased the field drying rate compared to no conditioning. Subsequent crimper conditioning applied to windrows also increased drying rate but caused greater DM losses than conditioning applied at mowing. Meanwhile, Rotz and Sprott (1984) noted that drying rates were not significantly different among cutterbar, flail, rotary disk and rotary drum mowers, and between roll and flail conditioners. However, shatter loss of leaves was 3 percentage points higher for the flail mower conditioner than for the roll conditioning devices. According to Shinners et al. (1991), leaf loss associated with four different types of conditioning rolls was practically the same (5.2 to 5.9% of DM) while drying rates were also similar between roll types. Koegel et al. (1985a) observed greater loss in second and third alfalfa cuts (16.8%) than in first cut (8.5%). During the second and third cuts, a haying system based on a flail-type conditioner had more loss (18.6%) than a system using a fluted-roll conditioner (16.5%) but no important difference was observed in the drying rate. Desiccants such as potassium carbonate can also be added at the conditioning step in order to speed up drying (Akkharath et al., 1996). Such treatments increase the drying rate of alfalfa hay but they are seldom used because of their cost and the logistical problem of filling regularly a spraying tank during mowing operations.

Alfalfa hay produced after maceration under good field drying conditions demonstrated an increased digestibility of neutral detergent fibre (NDF) and acid detergent fibre (ADF), according to Agbossamey et al. (2000). However, when rain occurred during field wilting, losses were greater for macerated alfalfa compared to traditional windrows because of increased leaching of soluble nutrients (such as Ca and Mg) and increased respiration (Savoie et al., 1993a). In a study in Wisconsin, losses were less than 10%, and maximum drying rate was obtained with macerated mats less than 0.64 cm in thickness (Shinners et al., 1985). In an experiment conducted by Savoie et al. (1993b), macerated alfalfa dried faster than conventional windrows with final moisture contents of 26.5 and 61.3%, respectively, after 28 h of field wilting. However, macerated forage had higher mechanical losses (7.8%) than conventional windrows (3.5%).

Windrow handling

Tedding and raking operations are necessary to aerate windrows and prepare them for subsequent collecting by a baler or a forage harvester. Tedders have a vigorous action of spreading and lifting up windrows and making them fluffy; they are designed to be used early in the drying process when the crop is wet and less sensitive to breakage (Macdonald and Clark, 1987). Rotz and Muck (1994) reported losses ranging between 1 and 3% for tedding which is similar to the 1 to 2% range reported by Rotz and Abrams (1988). Klinner et al. (1971, cited by Rees 1982) reported a greater range of tedding losses up to 8%. Dry matter losses are greater for legumes than for grass hay (Rotz and Muck, 1994). Based on laboratory results, tedding losses were six times greater for alfalfa than for grass hay; losses increased as moisture content decreased and could be over 20% for very dry legumes (Savoie, 1988). This explains why tedding is more commonly used in Europe where grass is dominant while in North America alfalfa is the more common hay species (Macdonald and Clark, 1987).

Rakes are used to displace the windrow and expose the wetter bottom portion for improved aeration and drying. The windrow is usually narrowed to facilitate pickup by the baler or forage harvester (Macdonald and Clark, 1987). Raking losses can be highly variable, ranging between 1 to 20% (Rotz and Muck, 1994), but they are typically within a range of 3 to 6% (Rotz and Abrams, 1988). Losses are influenced by moisture content and yield. According to Buckmaster (1993), relative raking losses are reduced when hay is wetter or yield is greater (1.4% less loss per 1000 kg/ha of yield increase). Raking losses may reduce the nutritive value of forages, especially legumes, because of the higher proportion of nutritious leaves that shatter compared to fibrous stems that remain in the windrow (Rotz and Abrams, 1988; Buckmaster et al., 1990). In an experiment by Rotz and Abrams (1988), measured losses were 3.5% for raking a full swath into a windrow, 0.8% for simply turning a windrow with a rake, 1.8% for picking up a windrow with a baler pickup and 1.1% within the baler. In the same experiment, losses of the highest quality material (leaves) were observed in the bale chamber. Buckmaster et al. (1990) estimated that the greatest monetary value of mechanical losses occurred during raking, followed by baling, forage harvesting and mowing-conditioning, corresponding to relative losses of 7.1, 5.4, 4.1, and 2.2%, respectively.

Baling

According to Rotz and Muck (1994), typical DM losses at baling range between 2 and 10%. Honig (1980, cited by Rees 1982) reported losses at baling ranging between 4.4 and 11.1%. In a study by Koegel et al. (1985a), DM losses from a round baler with a fixed chamber (10.8%) were greater than losses from a small rectangular baler (2.8%) and a round baler with a variable chamber (3.8%). Chamber losses were less in a mid-size rectangular baler (0.7%) than in a small rectangular baler or a large round baler (1.6% each), according to Shinners et al. (1996). Rotz and Muck (1994) reported chamber losses for small rectangular balers ranging between 1 to 3%. Rotz and Abrams (1988) measured losses of 1.8% at the baler pickup and 1.1% in the bale chamber of a small rectangular baler. Rotz (1995) reported baler losses at pick up between 1 and 3% based on other studies (Koegel et al., 1985a; McGechan, 1989; Shinners et al., 1992).

A bottom-fed baler for small rectangular bales, tested by Shinners et al. (1992), had slightly less pickup losses (1.1 vs. 1.3%), less bale chamber losses (2.3 vs. 2.7%) and more leaves retained than a side-fed baler.

Oxidative and leaching losses

When plant respiration occurs, non structural carbohydrates are metabolized into CO_2, water and heat by plant cells and epiphytic microorganisms (Rotz and Muck, 1994). These reactions cause DM disappearance. If the generated heat is not dissipated outside, it will accumulate inside the forage and may even, in some circumstances, cause self-ignition (Coblentz et al., 2010). Mechanical and oxidative losses are somewhat interlinked. Some mechanical treatments increase the susceptibility of crop components to respire or absorb rain water; hence these soluble cell constituents are more easily lost by leaching and oxidation afterwards. Table 1 presents a summary of reported values for mechanical losses during hay making operations.

Table 1: Dry matter losses as a function of hay making operations

Operation / Factor	Reported losses (% of DM)	Reference
Mowing	1 to 3% 2 to 4%	Rotz and Abrams, 1988 Honig, 1980
Mowing height	Mowing at 10 cm instead of 5 cm reduced yield by up to 38% Mowing at 10 cm instead of 5 cm reduced yield by 13%	Belesky and Fedders, 1997 Thomas, 2007
Tedding	1 to 3% up to 20% for very dry legumes up to 8%	Rotz and Muck, 1994 Savoie, 1988 Klinner et al., 1971
Raking	3 to 6%	Rotz and Abrams, 1988
Baling	1 to 3% for small rect. baler 1 to 3% at pick up 4 to 11%	Rotz and Muck, 1994 Koegel et al., 1985a Honig, 1980
Total mechanical losses (excluding height factor)	6 to 27% (average 16%)	Koegel et al., 1985a

Field management to control losses

Good management can contribute to reduce field losses during haymaking. In the usual sequence of operations, the first decision is to determine the proper time to start mowing. On the one hand, lactating dairy cows benefit from early cut when herbage has a high level of energy. On the other hand, dry cows, beef cows and horses are usually fed more mature herbage to correspond to their metabolic need for fibre. This means that alfalfa may be mowed early at the bud stage for dairy cows or later at the flowering stage for dry cows. With grasses, the proper stage of development at harvest may be the boot stage or the heading stage depending on the type of hay required. Anderson (1976, cited by Fonnesbeck et al., 1986) estimated that DM digestibility of alfalfa was reduced by 0.3% per day of delay. Changes in fibre concentration and digestibility over time are also species-dependent and the rate of decline of digestibility increases with increasing growth temperature for all species (Thorvaldsson et al., 2007). The impact of DM digestibility loss will start early for dairy cows. However, this impact will appear later for animals requiring a forage with more fibre and less energy. Table 2 lists a number of questions that should be addressed before starting the haymaking process.

Sequence of operations and timing

Mechanical losses will be greater when handling drier material. For example, over a five-day period, tedding was applied once daily. Loss due to tedding was 0.5% on the first day and increased to 4.5% on the last day of the experiment, with an average of 1.5% per handling operation (Overvest and Schukking, 1974 in McGechan, 1989).

Models have been developed to help farmers choose the proper timing for each field operation and thereby reduce losses caused by weather damage. One of the first models to predict field drying of hay was developed in Canada by Dyer and Brown (1977). It predicted drying based on potential evapotranspiration estimated from rainfall and dew. A multi-layer model based on heat and mass balance was developed by Tuzet et al. (1993). The model used weather data, biological characteristics of the plant and physical parameters of hay to predict moisture evaporation. Barr and Brown (1995) predicted drying with the Penman-Monteith equation based on solar radiation, air temperature, humidity, wind and rainfall. This model predicted DM and quality losses. Another model for hay drying was developed in Australia (Gupta et al., 1990) involving five sub-models: one for pasture growth, one for drying, one for losses (at cutting, during drying, raking, baling and losses in digestibility), one for the weather forecast and one for management. Models have to be adapted to local forage species, weather conditions and livestock feed requirements to provide proper advice to farm managers during haymaking.

Weather forecasts and decisions to carry out operations

Rain can leach soluble nutrients from forage and reduce digestibility (Collins, 1983; Rotz and Abrams, 1988). The level of loss will depend on forage moisture content, swath density and amount of rainfall (Rotz et al., 1991; Collins, 1983). Dernedde and Wilmschen (1969, cited by McGechan, 1989) measured 1% DM loss in runoff from hay initially at 20% moisture; the amount of loss doubled when hay had previously been lacerated. When respiratory losses were included, total DM disappearance due to both oxidation and leaching was as high as 16% in laboratory experiments. Rain loss ranged between 3 to 34% of DM and averaged 11.2 % with alfalfa hay (Rotz and Abrams, 1988).

Farmers can delay harvest to avoid rain damage. Delaying harvest will normally result in a lower nutritive quality of the standing crop because it becomes more fibrous and less digestible as it matures (Conseil Québécois des Plantes Fourragères, 2002). For example, a one-week delay in mowing timothy after late heading in spring growth reduced the *in vitro* digestibility of DM (-7%) and NDF (-10%), and increased NDF concentration (+5%) according to Pelletier et al. (2008). However, losses due to rain may be greater than losses due to delayed harvest. In the case of coastal bermudagrass, Hart and Burton (1967) reported a 0.25% loss per day in digestibility when mowing was delayed between the third and eighth week of growth while a 2.5 cm rainfall caused 7 to 10% digestibility loss. According to this estimate, a harvest delay up to six weeks is preferable to the digestibility loss caused by up to 2.5 cm rainfall. In the case of alfalfa, Fonnesbeck et al. (1986) found that hay quality was reduced by rain to a greater extent than by a one week advance in maturity. Plant cell wall constituents increased from 38.1 to 41.6% in an extra week of maturity while they increased from 39.4 to 43.6% after a 20-mm rainfall. So the decision of delaying mowing when heavy rain (> 15 mm) is forecast appears to be sound for several forage species.

Handling rained-on windrows

Despite all precautions that may be taken such as delaying mowing when rain is forecast, some windrows are likely to receive a shower of rain occasionally (Fonnesbeck et al., 1982). Leaching losses are less important when the amount of rain is light or when rainfall occurs quickly after mowing (Smith and Brown, 1994). So it may be acceptable to mow even if some light showers are forecast, especially when good weather is expected afterwards and large areas of forage still need to be harvested. Leaving forage in a narrow windrow provides better protection against rainfall loss than leaving hay in a widely spread swath (Savoie et al., 1993a). The windrow will have to be spread out again after rain to improve the drying process. Afterwards, the farmer will have to determine if the crop can still be salvaged as a moderate quality feed (e.g. for dry cows) or for non-feed uses (bedding). In any case, the crop must be removed to make way for the next growth.

Harvesting wet hay to reduce weather risk

Baling hay before it is completely dry, i.e. below 20% moisture, will reduce field DM loss compared to baling very dry hay which has become very brittle. Early baling will also reduce total field exposure time, field respiration loss and the risk of having rained-on hay (Rees, 1982). Different storage techniques such as barn ventilation and antifungal additives must be considered to conserve wetter hay.

Storage loss is largely influenced by moisture content (McGechan, 1990). The heating of bales in storage can cause further nutritive loss (Buckmaster et al., 1989, Collins et al., 1987). Heating usually increases with moisture and bale density (Buckmaster et al., 1989). In an experiment with alfalfa hay stored during 60 days, 89% of DM was recuperated from bales initially at 20% moisture and 84% of DM from bales initially at 30% moisture (Coblentz et al., 1996).

Moisture enhances the growth of heat-generating microorganisms. Temperatures as high as 77^{o}C were measured in alfalfa-orchardgrass large round bales (Coblentz and Hoffman, 2009a). Maximum temperature was negatively correlated with DM recovery and *in vitro* true digestibility. The maximum DM loss measured during storage was 15% in bales that had high moisture contents (26.7 to 46.6%).

Table 2: Management points to consider in controlling field losses of hay.

Are weather forecasts available for the decision-making process?
When should forage be mowed with regards to its maturity?
At what time of the day should forage be mowed (i.e. morning or evening; Pelletier et al., 2010)?
What area should be mowed in a single day?

Should mowed forage be left in a narrow windrow or a large swath?

When should windrows be tedded?

When should windrows be raked?

At what moisture content should hay be baled?

What shape and density of bales are optimal?

What are the best machinery adjustments?

Is hay fed on the farm? If sold, what is the market (dairy, beef, horse, etc.)?

Storage options

Several storage options are available to the farmer. When hay is very dry at harvest, i.e. less than 15% moisture content, there is practically no mold growth (Couture et al. 2002). Hay will then conserve almost indefinitely as long as it is protected against re-humidification. When hay is stored in conditions above the mold-growth threshold, then storage losses will increase as a function of moisture, oxygen availability and micro-organism activity (McGechan, 1990). One of three approaches can be followed to limit storage losses: 1) reducing moisture content quickly; 2) closing off the supply of oxygen; 3) destroying micro-organisms. Either approach will substantially inhibit biological reactions and minimize DM loss. Table 3 presents some of these options to reduce storage losses.

Additives to inhibit hay spoilage

Additives are sometimes used to inhibit microbial growth. Rectangular bales with moisture content as high as 28% have been preserved adequately with ammonia applied at a rate of 1.1 to 2.5% of total wet mass. Color characteristics of hay were improved when moisture content was below 25%. Large round bales either treated with ammonia or untreated and sealed with plastic film were preserved at much higher moisture contents, sometimes as high as 55 to 60% (Koegel et al., 1985b; Shinners et al, 2009a). When hay is sealed with a plastic cover, moisture becomes almost irrelevant with respect to DM loss.

Storage losses were reduced in mid-size alfalfa bales (35 x 50 x 90 cm) that were treated with propionic acid without plastic film. The treatment was effective in bales having between 25 and 38% moisture content but the effects were not consistent as far as quality was concerned (Buckmaster and Heinrichs, 1993). Adding 1.3% of urea to alfalfa round bales at 26% moisture reduced temperature, non enzymatic browning, mold growth and chitin content. It increased NDF and ADF after a five-month storage period but there was no negative impact on forage digestion, milk yield and milk composition when the hay was fed to dairy cows (Alhadhrami et al., 1993).

Microbiological additives have also been used. The maximum temperature reached in baled alfalfa hay was reduced by 15^{o}C when treated with an inoculant compared with untreated hay (Dulcet et al., 2006). The addition of exogenous fibrolytic enzymes such as endoglucanases and exoglucanases improved the degradability of NDF by up to 21% in alfalfa hay (Eun et al., 2007).

In barn ventilation or drying

Another approach to high moisture hay conservation is to remove excess moisture with in-barn drying or natural ventilation. Total DM loss during in-barn drying is usually less than 5% but can be as high as 15% under certain conditions (Segler, 1958 in Rees, 1982; Dijkstra, 1964 in Rees, 1982). Parker et al. (1992) successfully dried small rectangular alfalfa hay bales initially at 37% moisture with forced heated air. Bales were of adequate quality for dairy cattle but would not meet quality standards for horses because of the presence of some mold. Authors indicated the difficulty to monitor hay bale drying because of occasional non uniform airflow and gradual drying across the stack. Some bales had to be over-dried before all bales were dry enough for good conservation. When hay bales are ventilated with unheated ambient air, it is recommended to make low density bales, typically in the order of 100 to 140 kg DM/m^3. Low density facilitates airflow across the bales and rapid removal of excess moisture (House and Stone 1988).

Wrapping bales

Harrigan and Rotz (1994) reported different levels of DM loss for alfalfa round bales stored outside: 9.6% with plastic cover, 16.3% with net wrap and 16.5% with twine. The control hay stored inside with twine had 6.0% DM loss. Losses in quality, as measured by ADF, NDF and acid detergent insoluble N generally followed the same order. Shinners et al. (2009b) observed less DM loss from net-wrapped large round alfalfa bales compared to twine-wrapped bales stored outside. They also noted that avoiding direct ground contact of bales further reduced DM loss. Large round bales of alfalfa and brome grass had less loss when they were produced at a higher density (Russell et al., 1990). Loss during inside storage of round and rectangular bales was about half of the loss observed outside (Buckmaster et al., 1990). During three months of indoor storage, alfalfa hay in round and rectangular bales had similar DM losses but round bales had greater NDF at the end (Collins et al., 1987). Bales wrapped with plastic mesh had less NDF, less ADF, less acid insoluble N and less DM loss in the 30-cm outer layer than twine-wrapped bales (Russell et al., 1990). Feeding and handling losses were 25% with uncovered round bales stored outdoors, 14% with covered bales stored outdoors and 12% with uncovered bales stored indoors (Belyea et al., 1985, cited by Buckmaster et al., 1990).

Storage losses

Losses of DM during inside storage of hay usually range between 2 and 5% (Rotz and Abrams, 1988). For alfalfa hay stored outside during three months, Collins et al. (1987) reported 9.1% loss of DM and 13.6% loss in digestible DM. For similar bales stored inside, DM loss was 3.8% and digestible DM loss was 7.5%. Buckmaster et al. (1990) estimated that average DM loss during hay storage was 2.8% but the monetary value of those losses was greater because changes in quality contributed to reduced digestibility. Rotz and Abrams (1988) reported 4.5% DM loss on average for dry hay (11 to 20% moisture) and 10.9% DM loss for wet hay (25 to 34% moisture). Buckmaster and Heinrichs (1993) calculated that storage loss increased by 0.7% for each additional percent of moisture at baling. Concentrations of NDF, ADF, hemicellulose, cellulose, and lignin increased with increasing maximum storage temperature (Coblentz and Hoffman, 2009b). Rotz and Muck (1994) estimated that crude protein was lost at a steady rate of about 0.25% units per month of storage. More recently, McCormick et al. (2011) observed that round bales of bahiagrass conserved as hay (16% moisture) had 12.8% DM loss when stored outside and 2.9% DM loss when stored inside. Forage quality expressed as net energy of lactation was initially 1.36 Mcal/kg at harvest; it deteriorated more in hay bales stored outside (1.17 Mcal/kg) than hay bales stored inside (1.32 Mcal/kg). This difference was reflected by a 7% lower milk production from dairy cows fed outside-stored hay compared to inside-stored hay (28.2 vs. 30.2 kg milk/day). These authors also evaluated bahiagrass baleage at 50% moisture content which had similar quality (1.32 Mcal/kg) to inside-stored hay but slightly lower (4%) milk response (29.0 kg milk/day).

Table 3: Management points to consider when storing hay bales.

Should additives be used? Which one, when, and at what rate should it be applied?
Is barn-ventilation or heated air drying available to conserve wet hay bales?
If not, how should bales be stored?
Is bale wrapping available to deal with wet bales?
During storage, what should be done if wet hay is exposed to air?
Is there a disposal system for used plastic wrap?

Cost of hay making

The cost of hay making can be viewed basically from three different perspectives: 1) hay is produced on the farm for internal use; 2) hay is produced on the farm for external use; 3) hay is produced outside the farm and purchased for internal use. When a farmer produces his own hay to feed his livestock, he can reduce the cost by increasing yield, increasing total area cultivated in forage, and decreasing both quantitative and qualitative losses. When a farmer buys hay from the outside, he has less control on costs which are influenced by the local market price fluctuations.

For example, in a free market like the United States, prices of hay vary considerably from one year to the other, and also seasonally. The yearly average price for hay (all types) in 2003/2004 was $85.50/ton while in 2008/2009 it was $152.00/ton, a record high (USDA, 2011a). Prices were back to $108.00/ton in 2009/2010. When a farmer buys all his hay from the outside, he has to expect such variations. On many dairy farms in North America, hay has become a small input in the total forage ration (e.g. less than 10% hay is combined with more than 90% farm grown silage). In such cases, the farm would not be much affected by hay price fluctuations. However, if hay is a large part of the ration, it would be preferable to produce it on the farm to maintain greater independence with regards to hay price fluctuations.

When hay is produced on the farm, the total production cost will be sensitive to changes in the price of labour, energy, machinery, fertilizers and other inputs. In recent years, the price of several farm inputs has increased considerably. During the period from 2002 to 2008, prices paid in the United States for diesel increased form $0.96/gallon to $3.62/gallon (USDA, 2011b). The price for superphosphate increased from $221/ton to $800/ton (USDA, 2011c) and the price for nitrogen (44-46% urea) increased from $191/ton to $552/ton (USDA, 2011d). The production cost of hay on the farm has therefore increased markedly. Farmers producing their own hay have some management options to control such input price increases. They can consider legume-grass mixtures or crop rotations to reduce N-fertilizer costs. They can increase forage yields with better seeds or increase total cultivated area in forages to reduce fixed and variable costs. In the end, the total cost of hay making will depend on the quantity and quality of forage harvested and stored, and the resources required to feed it to livestock or the income that may be generated from selling some hay on the market.

Conclusion

Hay systems can be subject to important losses in the field and during storage. Mechanical field losses occur at mowing, conditioning, windrow handling and baling. Under good management practices, mowing-conditioning can cause dry matter (DM) losses within 1 to 3% of total yield; windrow handling losses due to tedding and raking are typically within 3 to 6%; baling losses are within 2 to 11% depending on baler type and dryness of crop at the time of pickup. Therefore, total DM losses due to mechanical treatments may vary between 6 and 20%. Meanwhile, non-mechanical or invisible losses occur as a result of normal plant oxidation and leaching when rainfall occurs on the exposed windrows. Theses invisible losses typically range between 2 and 10%; they will be very low when hay dries quickly under sunny conditions but they will increase when hay dries slowly in the field under occasional rain. Once in storage, hay may lose additional DM due to respiration and mold growth. Storage losses have been observed to range between 5 and 10%, depending on moisture, storage time, and whether stored inside or outside.

Since most losses come from the highly nutritive leaves and the easily oxidized sugars (i.e. the non structural carbohydrates), the nutritive value of forage is also reduced during the hay making process. When large amounts of rain are forecast, it is better to postpone mowing to avoid important leaching losses even if a mowing delay implies harvesting a slightly more mature and less digestible crop. When local soil conditions allow mowing forage close to the ground, a low cut (5 cm above the ground) is preferable to a high cut (10 cm above the ground) because of higher harvested yields (10 to 30% over several cuttings) and only a small reduction of feed quality due to increased fibre.

Stable conservation of hay requires low moisture content, ideally below 15% to avoid any mold development. If hay is harvested at a higher moisture content, various options should be considered: the use of antifungal additives, in-barn ventilation of hay bales or wrapping bales to ensure an anaerobic environment. Overall, field losses are usually greater than storage losses in haymaking. Losses can be reduced by a variety of management decisions. These include the time to start mowing, the use of weather forecasts to minimize the risk of rain during field wilting, the type of windrow handling, the time to bale, the use of additives to inhibit mold growth, barn drying to lower moisture content or the use of plastic wrap to create an anaerobic seal.

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