Storage Characteristics of Large Round and Square Alfalfa Bales: Low-Moisture Wrapped Bales

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Abstract. *Substantial dry matter (DM) and quality losses have been reported for partially dried alfalfa that has been rained on before moisture reduction to levels acceptable for dry hay storage. The objective of this research was to determine the feasibility of preserving alfalfa baled at less than 45% moisture (w.b.) by wrapping in plastic film. Large round and large square bales were preserved as individually wrapped or tube wrapped silage bales at two moisture ranges: approximately 40% to 55% and 30% to 40% w.b. The tube wrap system was 50% more productive while requiring 43% less plastic compared to individually wrapped bales. Storage characteristics were quantified by DM loss, change in nutrient composition, fermentation products, and heating after removal from storage. Average DM loss during storage was 3.5% and 2.3% for the high and low moisture ranges, respectively. There were generally no significant differences in DM losses or nutrient retention between round and square bales, bales wrapped individually or in a tube, or high and low moisture ranges. Fermentation products were significantly affected only by initial moisture content. Heating rate of the low moisture silage bales after removal from storage was acceptable, taking seven or more days to heat to 35°C. Although below the moisture range usually considered acceptable for chopped silage in bunk or bag silos, preservation of bales at both moisture ranges was excellent despite the low production of desirable fermentation products.*

Keywords. *Alfalfa, Bales, Ensiling, Round bales, Silage, Wrapping.*

The large round bale (LRB) is the most common way that hay for ruminant animals is packaged and stored in North America. The LRB is used primarily to feed beef animals but is also used for young stock and dry cows in the dairy industry. A major reason the LRB is attractive to beef producers, many of whom are part-time or lifestyle farmers, is that bales can be stored outdoors, virtually eliminating storage capital costs. To avoid excessive losses from biological activity during storage, alfalfa or grass hay should be below 20% wet basis (w.b.) moisture (Pitt, 1990; Rotz and Muck, 1994). Field curing of dry hay in swaths or windrows can take many days depending on yield, weather conditions, and conditioning treatments. Typical losses from respiration and rain were estimated to be 15% to 25% of the crop DM, with longer field curing time resulting in greater losses (Rotz and Muck, 1994). Outdoor storage of LRB subjects the hay to additional losses from precipitation, which can leach soluble nutrients from the outer layer of the bale and also support microbial activity. Outdoor storage losses for LRB ranged from 5% to 25% of total DM (Russell et al., 1990; Bledsoe and Bates, 1992; Harrigan and Rotz, 1994; Collins et al., 1995; Shinners et al., 2009).

An alternative to producing dry hay and storing LRB outdoors is to bale the crop at higher moisture, wrap it in plastic film, and preserve it by fermentation. The main advantage of bale silage is that forage can be harvested with much less field drying time, reducing exposure to damaging rain. The recommended range of moisture for successful ensiling of chopped material stored in silos is approximately 50% to 67% w.b. (Pitt, 1990). Chopped forage stored in silos below 50% moisture is discouraged because of the likelihood of heating and respiration (Muck, 1988). Most recommendations for baled silage are in the range of 50% to 60% w.b. (Place and Heindrichs, 1997; Lingvall, 1995; Garthe and Hall, 1996). Many producers of dry hay would consider producing baled silage when weather conditions make it unlikely that dry hay moisture can be reached without exposure to rain, but the current moisture recommendations require that producers make this decision very early in the drying period. Huhnke et al. (1997) successfully produced individually wrapped bale silage at moistures as low as 25% w.b. If forage in the range of 30% to 45% w.b. moisture can be preserved by baling and wrapping in plastic film, then North American forage producers can have an alternative harvest practice when weather threatens a successful harvest as dry hay. The specific objectives of this research were to determine plastic film use, productivity, and storage characteristics of individually wrapped and tube wrapped large round and large square silage bales stored at moisture ranges below those typically deemed acceptable for chopped and ensiled alfalfa.

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Materials and Methods

In 2000, three treatments were tested: alfalfa bales individually wrapped at 30% to 40% w.b. moisture and tube wrapped at moistures of approximately 40% to 50% and 30% to 40% w.b. The bales were wrapped with net wrap during baling. First-cutting alfalfa at about one-half bloom was cut on 3 June. The high and low moisture ranges were baled on 6 and 7 June, respectively. Drying conditions were considered good; however, a 10 mm shower occurred the night after cutting. Second-cutting alfalfa at about one-third bloom was cut on 5 July. The high and low moisture ranges were baled on 6 and 7 July, respectively. Drying conditions were considered good with no precipitation.

All bales were formed with a John Deere model 457 Silage Special round baler with bale diameter set at 130 cm. The baler was operated at about 8 km/h with the belt tension set to maximum. The variable density core option was not activated, so belt tension was the same throughout the bale formation. All bales were transported to the storage area, sampled, and wrapped in seven layers of 1 mil plastic stretch film with 50% overlap within roughly 4 h of formation.

The bales were weighed on a platform scale to the nearest 0.5 kg using a 1,800 kg capacity scale. Two samples each for moisture and nutrient determination were collected to a depth of about 50 cm using a 5 cm diameter boring tube. The four samples were collected from the shoulder of the bale at a 45º angle to the bale radius. Moisture samples were oven dried at 103ºC for 24 h and nutrient samples at 65ºC for 72 h (*ASAE Standards*, 2001). All boreholes were then plugged with a 5 cm diameter PVC pipe capped at both ends.

The productivity of the individual (McHale model 995LS) and tube (H & S model LW2) bale wrappers was determined by total wrapping time. For the individual wrapper, this was the total time from one bale to the next, including time to maneuver the tractor and wrapper into position after depositing the previous bale. For the tube wrapper, this was the total time between bales being placed on the wrapper. An experienced operator was used to operate both wrappers, and seven layers of 1 mil stretch film with 50% overlap was used. Wrapping time was collected for 12 bales with each wrapper.

A sacrificial bale wrapped in film using the individual bale wrapper was placed at both ends of the tube wrapped bales. All bales were placed directly on the soil on level ground that had previously been a grass pasture. The grass around the bales was periodically trimmed, and all bales were periodically inspected for damage. Holes were repaired with film repair tape.

First-cutting bales were removed from storage after 154 days on 4 November 2000, and second-cutting bales were removed after 364 days on 5 July 2001. As bales were removed from storage, they were weighed using the same equipment and procedure as described above. The plastic surrounding each bale was collected and weighed to the nearest 0.05 kg on a 45 kg capacity scale. Bales were bored to a depth of about 50 cm in four locations using the same boring device described above. Three radial samples were taken from each side at the 3 and 9 o'clock positions. Two subsamples were oven dried at 65°C for 72 h for moisture determination. Two subsamples were oven dried at 65°C so they could be analyzed for crude protein (CP) (using a Leco FP-2000A nitrogen analyzer, Leco Corp., St. Joseph, Mich.), acid detergent fiber (ADF), and neutral detergent fiber (NDF) (using wet laboratory techniques; Hintz et al., 1995). The final two samples were frozen for analysis of pH and fermentation products using wet laboratory and high-performance liquid chromatography techniques (Muck and Dickerson, 1988).

In 2001, eight treatments were tested: individually wrapped and tube wrapped bales at high and low moisture ranges (~40% to 55% and ~30% to 40% w.b., respectively) using both LRB and large square bales (LSB). All LRB were wrapped with net wrap at bale formation using the same baler as in 2000. The LSB were formed with a Case IH model 8575 baler (80 × 88 cm cross-section). Bale length was set for about 170 cm. First-cutting alfalfa at one-quarter bloom was cut on 28 May and baled on 29 and 30 May 2001. Second-cutting alfalfa at one-half bloom was cut on 11 July and baled on 12 and 13 July 2001. For both cuttings, drying conditions during field wilting were considered good, with no precipitation. The weighing and boring techniques were the same as described above. The LSB were bored from both ends to a depth of 50 cm to obtain moisture and nutrient samples, and boreholes were plugged with PVC pipe as described above. First-cutting bales were removed from storage after 157 days on 2 November 2001, and second-cutting bales were removed after 348 days on 25 June 2002. The procedures for bore sampling, oven drying, and laboratory analysis described above were the same in 2001 and 2002.

When bales were removed from storage in the summer of 2002, one LRB and LSB from both the high and low moisture ranges were placed inside a laboratory, and two thermocouples per bale were placed at a depth of about 25 cm. Bale interior and ambient temperatures were recorded in the early morning and mid-afternoon over a 10-day period.

A single-factor analysis of variance was conducted on all the trials to determine statistically significant differences between treatments. A two-way analysis of variance was used to block confounding effects when analyzing data across more than one variable. Statistical differences were based on a least significant difference (LSD) with a probability of 95% (Steel et al., 1996).

Results

The tube wrapper was twice as productive as the individual wrapper. The average wrapping time per LRB bale was 46 and 92 s for the tube and individual wrappers, respectively (LSD = 10 s, $P = 0.05$). The tube wrapper required roughly half the mass of plastic per kg hay DM as individually wrapped bales (table 1). The productivity and plastic use improvements occurred because the tube wrapper only wraps the circumference of the bales, not the ends. The two bale ends added about 50% more surface area to be wrapped, but plastic use about doubled because many more layers than needed are overlaid at the center of the ends. Another observed advantage of tube wrapping was that much less storage space was required compared to individually wrapped bales. Individually wrapped bales could have been stacked to reduce storage space, but this would have required an additional operation. A single person could load and operate the fully automated tube wrapper, while two people were needed to load and operate the individual wrapper. The LSB required more plastic film per kg DM than LRB (table 1), partly because the shoulders of the LSB needed more overlap to produce a good seal and partly because of the surface-to-volume

Table 1. Mass of plastic film used per unit mass of hay DM.

		Plastic Use (g per kg DM)	
		2000	2001
Individual	LRB	9.3 b	11.4 b
	LSB	--	17.2 c
Tube	LRB	4.5 a	7.5 a
	LSB	--	12.5 b
LSD[a] (P = 0.05)		1.2	1.6

[a] Averages within columns followed by different letters are significantly different at the 95% confidence level. Data for first and second cutting were combined and analyzed by two-way analysis of variance.

ratio, which favored the LRB over the LSB (4.57 vs. 5.95 m^2/m^3). The reduction in plastic from the use of the tube wrapper was less with the LSB because the ends represented a smaller fraction of the total surface area compared to the LRB.

In all trials, the bales had a familiar ensiled odor when removed, and only very few minor incidences of mold were observed. Some of the observed mold was due to undetected holes in the film. This was more of a problem with the LSB than the LRB, especially at the corners of the LSB where the sharp ends of cut stems poked through the film. In all cases, holes in the film caused only localized spoilage. There was no evidence that a hole in the film caused spoilage throughout, as has been reported when bales were stored in bale bags or stacked under a plastic tarp (Straub et al., 1990). Minor surface mold was occasionally found where there were no obvious holes in the film, typically on the ends of the bales wrapped in the tube, especially where the bales were not butted tightly together. The removed bales were opened, and there was virtually no internal mold observed.

If the bales were properly wrapped so that moisture could not escape, then loss of DM from respiration would have resulted in a rise in moisture because stoichiometrically 60% of the mass of the respired carbohydrates would have remained in the bale as H_2O (Pitt, 1990). The average absolute difference between the final and initial bale moisture was 1.3 percentage units for all bales, suggesting a theoretical loss from respiration of 2.5% to 3.2% from 25% to 50% (w.b.) initial moisture content. Actual average DM loss was 2.3% and 3.5% for the low (~30% to 40% w.b.) and high (~40% to 55% w.b.) treatments, respectively.

There was no evidence of moisture equalization within the tube between bales of different initial moisture. For instance, a total of four tubes were made in 2001, and in each tube there was a high and low moisture bale directly adjacent to each other. When placed into storage, the difference between adjacent bales at high and low moisture averaged 14.2 percentage units. Yet when removed from storage, both the high and low moisture bales gained an average of 1.1 percentage units of moisture content, indicating that there was little migration of moisture from the high to low moisture bales. The average measured DM loss for these eight bales was 2.5%, which corresponds exactly with the theoretical DM loss that would occur from a 1.1 percentage change in bale moisture.

There were generally no differences in DM loss between treatments in 2000 or 2001, and losses were less than 7% even after 11 months in storage (tables 2 through 4). Average DM loss across all treatments, cuttings, and years was 2.8%. Losses tended to be slightly higher for first-cutting bales than for second-cutting bales (tables 2 through 4), even though the second cutting was stored more than twice as long before opening. There was a consistent trend for lower DM loss at the lower moisture range, but the differences were small and not statistically significant. In 2001, there was a slight trend for lower losses with LRB compared to LSB and with tube compared to individually wrapped bales, but these differences were also not statistically different (tables 3 and 4).

Losses of chopped forage stored in tower, bunk, or bag silos have been reported to range from 5% to 20% depending on such management factors as moisture, packing density, and feed-out rate (Pitt, 1990; Muck and Rotz, 1996; Muck and Holmes, 2000). Losses with wrapped bale silage have been reported to be less than this, typically in the range of 3% to 12% (Huhnke et al., 1997; Shin, 1990; Kennedy, 1987). It is well known that attempting to ensile low moisture (<40% moisture) chopped forage can cause high levels of DM loss, excessive heating, and even silo fires (Pitt, 1990; Muck, 1988). In this study, DM loss with low-moisture wrapped bales was less than 7% in all four trials, with an average of 2.8%. The trend for lower losses at lower moistures was similar to that reported by Huhnke et al. (1997). A major factor contributing to high DM losses of chopped forage in silos is the inability to exclude oxygen, especially at low moistures (Pitt, 1990; Muck, 1988). Preserving low-moisture forage in wrapped bales was very successful, even though there was little fermentation, because the tight plastic film prevented oxygen penetration. Many of the studies cited above determined DM loss over a relatively short period of storage, typically 2 to 6 months. In this study, DM loss for the two studies with 11-month storage period was 2.3%, showing the viability of long-term preservation of low-moisture wrapped for–

Table 2. Bale moisture,[a] DM loss, and fermentation products for alfalfa LRB formed in June (first cutting) and July (second cutting) 2000.

		Moisture (% w.b.)		DM Loss		Fermentation Products[b] (% of DM)		
	Bale and Wrap Type	Initial	Final	(% of total)	pH	Lactic Acid	Acetic Acid	Ethanol
First Cutting	LRB - Tube	41.1 b	43.2 b	4.3	4.94 a	2.49 b	0.68 b	0.59
(154 days	LRB - Tube	31.6 a	32.7 a	2.5	5.78 b	0.31 a	0.25 a	0.29
in storage)	LRB - Individual	30.8 a	31.5 a	1.9	5.90 b	0.02 a	0.16 a	0.35
	LSD[c] (P = 0.05)	3.5	3.1	3.2	0.28	0.62	0.14	0.33
Second Cutting	LRB - Tube	46.8 b	47.6 b	2.9	4.87 a	4.29 b	1.52 b	--
(364 days	LRB - Tube	36.3 a	37.4 a	2.4	5.24 b	1.48 a	0.45 a	--
in storage)	LRB - Individual	36.6 a	37.0 a	1.3	5.30 b	1.17 a	0.49 a	--
	LSD[c] (P = 0.05)	3.1	2.0	1.9	0.30	0.62	0.25	

[a] Average bale density was 183 and 210 kg DM/m^3 for first and second cutting bales, respectively.
[b] Undetectable levels of butyric acid across all treatments, and undetectable levels of ethanol across all second cutting treatments.
[c] Averages within columns followed by different letters are significantly different at the 95% confidence level.

Table 3. Bale moisture,[a] DM loss, and fermentation products for first-cutting alfalfa silage bales formed June 2001 and removed from storage after 157 days.

Moisture Range, Wrap Type, Bale Type	Moisture (% w.b.) Initial	Moisture (% w.b.) Final	DM Loss (% of total)	pH	Fermentation Products[b] (% of DM) Lactic Acid	Acetic Acid	Ethanol
High - individual - LRB	56.1 d	56.6 c	2.1 a	4.81 a	3.88 b	0.88 b	0.46 c
Low - individual - LRB	38.1 ab	39.0 a	3.0 ab	5.47 b	0.58 a	0.30 a	0.05 a
High - tube - LRB	54.9 d	56.4 c	4.9 ab	4.76 a	3.69 b	0.78 b	0.27 b
Low - tube - LRB	39.3 b	40.4 a	2.7 a	5.44 b	0.36 a	0.35 a	0.21 ab
High - individual - LSB	48.2 c	50.8 b	6.2 b	4.88 a	3.72 b	0.73 b	0.57 c
Low - individual - LSB	35.9 a	38.6 a	3.6 ab	5.43 b	0.22 a	0.34 a	0.21 ab
High - tube - LSB	49.4 c	50.9 b	4.7 ab	4.83 a	3.93 b	0.88 b	0.59 c
Low - tube - LSB	38.9 b	40.1 a	3.1 ab	5.49 b	0.58 a	0.39 a	0.26 b
LSD[c] (P = 0.05)	2.6	2.2	3.3	0.15	0.83	0.17	0.17
Tube[d]	45.6	47.0	3.8	5.12	2.14	0.59	0.32
Individual[d]	44.6	46.2	3.7	5.15	2.10	0.60	0.33
LSD[c] (P = 0.05)	1.3	1.1	1.7	0.07	0.42	0.08	0.08
LRB[e]	47.1 b	48.1 b	3.2	5.12	2.13	0.58	0.25 a
LSB[e]	43.1 a	45.1 a	4.4	5.16	2.11	0.61	0.41 b
LSD[c] (P = 0.05)	1.3	1.1	1.7	0.07	0.42	0.08	0.08
High moisture[f]	52.1 b	53.7 b	4.5	4.82 a	3.80 b	0.84 b	0.47 b
Low moisture[f]	38.1 a	39.5 a	3.1	5.46 b	0.43 a	0.35 a	0.18 a
LSD[c] (P = 0.05)	1.3	1.1	1.7	0.07	0.42	0.08	0.08

[a] Average bale density was 160 and 163 kg DM/m^3 for LRB and LSB, respectively.
[b] Undetectable levels of butyric acid across all treatments.
[c] Averages within columns followed by different letters are significantly different at the 95% confidence level.
[d] Data averaged across moisture level and bale type, analyzed with two-factor analysis of variance.
[e] Data averaged across moisture level and wrap type, analyzed with two-factor analysis of variance.
[f] Data averaged across bale and wrap type, analyzed with two-factor analysis of variance.

Table 4. Bale moisture,[a] DM loss, and fermentation products for second-cutting alfalfa silage bales formed July 2001 and removed from storage after 348 days.

Moisture Range, Wrap Type, Bale Type	Moisture (% w.b.) Initial	Moisture (% w.b.) Final	DM Loss (% of total)	pH	Fermentation Products[b] (% of DM) Lactic Acid	Acetic Acid	Ethanol
High -individual - LRB	50.8 b	52.1 c	2.9 ab	5.34 a	1.35 c	0.48 c	0.29 ab
Low -individual - LRB	33.7 a	35.3 a	2.0 ab	5.63 c	0.10 a	0.24 a	0.20 ab
High - tube - LRB	50.0 b	50.7 bc	1.6 a	5.33 a	1.45 c	0.41 bc	0.28 ab
Low - tube - LRB	34.2 a	35.9 a	2.6 ab	5.63 c	0.06 a	0.24 a	0.17 a
High - individual - LSB	46.2 b	48.4 bc	4.3 b	5.48 b	0.41 ab	0.27 ab	0.25 ab
Low -individual - LSB	35.8 a	37.4 a	1.6 a	5.60 bc	0.22 a	0.25 ab	0.31 b
High - tube - LSB	45.7 b	46.5 b	2.2 ab	5.46 b	1.03 bc	0.38 abc	0.28 ab
Low - tube - LSB	35.1 a	35.8 a	1.6 a	5.60 bc	0.13 a	0.24 a	0.18 a
LSD[c] (P = 0.05)	5.7	5.3	2.6	0.12	0.79	0.16	0.12
Tube[d]	41.2	42.2	2.0	5.50	0.67	0.32	0.23
Individual[d]	41.6	43.3	2.7	5.51	0.52	0.31	0.25
LSD[c] (P = 0.05)	2.9	2.7	1.3	0.06	0.37	0.08	0.06
LRB[e]	42.2	43.5	2.3	5.48	0.74	0.34	0.23
LSB[e]	40.7	42.0	2.5	5.53	0.45	0.29	0.25
LSD[c] (P = 0.05)	2.9	2.7	1.3	0.06	0.37	0.08	0.06
High moisture[f]	48.2 b	49.4 b	2.7	5.40 a	1.06 b	0.39 b	0.27
Low moisture[f]	34.7 a	36.1 a	2.0	5.61 b	0.13 a	0.24 a	0.21
LSD[c] (P = 0.05)	2.9	2.7	1.3	0.06	0.37	0.08	0.06

[a] Average bale density was 152 and 176 kg DM/m^3 for LRB and LSB, respectively.
[b] Undetectable levels of butyric acid across all treatments.
[c] Averages within columns followed by different letters are significantly different at the 95% confidence level.
[d] Data averaged across moisture level and bale type, analyzed with two-factor analysis of variance.
[e] Data averaged across moisture level and wrap type, analyzed with two-factor analysis of variance.
[f] Data averaged across bale and wrap type, analyzed with two-factor analysis of variance.

age. Borreani et al. (2007) reported DM losses of less than 2% for individually wrapped alfalfa bales at greater than 65% w.b. moisture.

Fermentation products were statistically lower and pH higher for the low-moisture treatments (tables 2 through 4). A pH of greater than 6.5 is generally recognized as evidence of spoilage even if mold formation is not observed (Pitt, 1990). None of the treatments had a pH greater than 6.0. Neither the system of film wrapping nor the bale type had a significant effect on pH or fermentation products (tables 2 through 4). Only moisture significantly affected pH and fermentation level. The trend of higher pH and lower fermentation products with lower moisture forages has been reported with laboratory silos (Muck, 1990), LRB grass silage (Shin, 1990; Huhnke et al., 1997), and LRB alfalfa silage (Nicholson et al., 1991). The typical ranges for pH, lactic acid, and acetic acid for chopped alfalfa stored in a silo is 4.3 to 4.7, 4.0% to 6.0% of DM, and 0.5% to 2.5% of DM, respectively (Kung and Shaver, 2000). Although lactic and acetic acid production was low, the presence of undesirable butyric acid was below detectable level (<0.01% of DM), similar to results reported by Huhnke et al. (1997). The low levels of acids and relatively high pH of the low moisture bales indicate that very little fermentation actually took place. However, DM losses were quite low, indicating that low-moisture forage can be well preserved without a high level of fermentation as long as the film limits oxygen penetration into the bale.

There were some initial compositional differences between treatments, but they were generally minor, with the greatest variation in initial composition in the last trial (tables 5 through 7). There were no significant trends for wrap type, bale type, or initial bale moisture to affect the change in nutrient composition during storage except for CP in 2001 by bale type in the first cutting and moisture in the second cutting. The magnitude of the fiber retention ratios was similar to those reported for the core of dry bales stored outdoors (Shinners et al., 2009). The magnitude of changes to fiber and protein concentrations was also similar to that reported for wrapped alfalfa bales ensiled at similar moistures to those studied here (Han et al., 2004; Hancock and Collins, 2006).

There was concern that low-moisture wrapped baled forage would have poor aerobic stability at feed-out because of the low levels of fermentation products produced. Heat gen–

Table 5. Initial nutrient composition and compositional change for alfalfa LRB formed in June (first cutting) and July (second cutting) 2000.

		Initial Nutrient Composition (% of DM)			Nutrient Retention Ratio[a]		
	Bale and Wrap Type	CP	NDF	ADF	CP	NDF	ADF
First Cutting (154 days in storage)	LRB - tube	21.5	46.2	33.9	1.02	1.05	1.03
	LRB - tube	21.7	46.9	34.6	1.03	1.07	1.04
	LRB - individual	21.4	48.2	34.9	1.05	1.07	1.09
	LSD (P = 0.05)	1.6	3.4	1.7	0.09	0.05	0.06
Second Cutting (364 days in storage)	LRB - tube	22.2	39.2	30.1	1.00	1.00	0.96
	LRB - tube	21.4	37.5	28.7	1.00	1.06	1.03
	LRB - individual	21.0	38.2	29.5	1.02	1.05	1.04
	LSD (P = 0.05)	1.3	3.1	2.4	0.07	0.10	0.10

[a] Ratio of constituent value out of storage to value into storage.

Table 6. Initial nutrient composition and compositional change for first-cutting alfalfa silage bales formed June 2001 and removed from storage after 157 days.

	Initial Nutrient Composition (% of DM)			Nutrient Retention Ratio[b]		
Moisture Range,[a] Wrap Type, Bale Type	CP	NDF	ADF	CP	NDF	ADF
High - individual - LRB	20.3	39.1	28.3	1.04	1.05	1.09
Low - individual - LRB	22.5	33.0	26.1	1.08	1.17	1.15
High - tube - LRB	21.3	33.4	26.3	1.14	1.10	1.08
Low - tube - LRB	22.3	35.8	28.4	1.01	1.02	1.03
High - individual - LSB	20.7	36.6	27.2	1.17	1.10	1.02
Low - individual - LSB	20.8	36.6	26.0	1.18	1.10	1.07
High - tube - LSB	20.0	36.3	26.1	1.19	1.09	1.08
Low - tube - LSB	19.8	36.9	26.8	1.14	1.07	1.06
LSD[c] (P = 0.05)	2.7	6.7	3.1	0.18	0.17	0.13
Tube[d]	21.1	36.3	26.9	1.12	1.11	1.08
Individual[d]	20.9	35.6	26.9	1.12	1.07	1.06
LSD[c] (P = 0.05)	1.3	3.3	1.5	0.08	0.09	0.06
LRB[e]	21.6 b	35.3	27.3	1.07 a	1.08	1.09
LSB[e]	20.3 a	36.6	26.5	1.17 b	1.09	1.06
LSD[c] (P = 0.05)	1.3	3.3	1.5	0.08	0.09	0.06
High moisture[f]	20.6	36.4	27.0	1.13	1.08	1.07
Low moisture[f]	21.4	35.6	26.8	1.10	1.09	1.08
LSD[c] (P = 0.05)	1.3	3.3	1.5	0.08	0.09	0.06

[a] Moisture contents presented in table 3.
[b] Ratio of constituent value out of storage to value into storage.
[c] Averages within columns followed by different letters are significantly different at the 95% confidence level.
[d] Data averaged across moisture level and bale type, analyzed with two-factor analysis of variance.
[e] Data averaged across moisture level and wrap type, analyzed with two-factor analysis of variance.
[f] Data averaged across bale and wrap type, analyzed with two-factor analysis of variance.

Table 7. Initial nutrient composition and compositional change for second-cutting alfalfa silage bales formed July 2001 and removed from storage after 348 days.

Moisture Range,[a] Wrap Type, Bale Type	Initial Nutrient Composition (% of DM) CP	NDF	ADF	Nutrient Retention Ratio[b] CP	NDF	ADF
High - individual - LRB	19.8 c	31.4 a	23.4 a	1.03 a	1.12	1.09 ab
Low - individual - LRB	17.9 a	37.8 b	27.7 b	1.11 ab	1.07	1.02 ab
High - tube - LRB	18.5 abc	37.3 b	27.8 b	1.03 a	1.08	1.05 ab
Low - tube - LRB	18.5 abc	33.9 b	23.7 a	1.18 b	1.16	1.16 ab
High - individual - LSB	18.1 ab	33.2 ab	23.7 a	1.08 a	1.02	1.03 ab
Low - individual - LSB	19.6 bc	36.1 ab	24.9 a	1.08 a	1.04	1.14 ab
High - tube - LSB	18.9 abc	35.8 ab	25.8 ab	1.12 ab	1.00	0.95 a
Low - tube - LSB	19.5 bc	32.3 ab	22.7 a	1.11 a	1.15	1.19 b
LSD[c] (P = 0.05)	1.4	5.5	3.5	0.09	0.20	0.23
Tube[d]	18.8	34.6	24.9	1.07	1.06	1.07
Individual[d]	18.8	34.8	25.0	1.11	1.10	1.09
LSD[c] (P = 0.05)	0.7	2.7	1.7	0.05	0.10	0.11
LRB[e]	18.7	35.1	25.7	1.09	1.11	1.08
LSB[e]	19.0	34.3	24.3	1.10	1.05	1.08
LSD[c] (P = 0.05)	0.7	2.7	1.7	0.05	0.10	0.11
High moisture[f]	18.8	34.4	25.2	1.06 a	1.06	1.03
Low moisture[f]	18.9	35.0	24.7	1.12 b	1.11	1.13
LSD[c] (P = 0.05)	0.7	2.7	1.7	0.05	0.10	0.11

[a] Moisture contents presented in table 4.
[b] Ratio of constituent value out of storage to value into storage.
[c] Averages within columns followed by different letters are significantly different at the 95% confidence level.
[d] Data averaged across moisture level and bale type, analyzed with two-factor analysis of variance.
[e] Data averaged across moisture level and wrap type, analyzed with two-factor analysis of variance.
[f] Data averaged across bale and wrap type, analyzed with two-factor analysis of variance.

eration is often used as an indicator of aerobic stability in silages, with the desired maximum temperature being about 35°C (Pitt, 1990). Aerobic deterioration occurs when baled silage is exposed to oxygen. Aerobic bacteria and other microorganisms dormant in the bale during storage can become active when exposed to oxygen after the film is removed. Lactic and acetic acids produced during fermentation suppress aerobic microbial growth. It took seven or more days for the temperature of the bales to exceed 35°C even though ambient temperature was quite high (fig. 1). This would likely be more than sufficient time for the bale to be consumed, so aerobic stability during feed-out would not appear to be a concern despite the low levels of fermentation products. It should be noted that the bales were left intact and not torn apart, as would be the case when the bale would be consumed. The high-moisture bales had less heating than the low-moisture bales because the former bales had greater level of fermentation acids. The pH, lactic acid, and acetic acid for the bales studied were 5.6, 0.10%, and 0.22% for the low-moisture bales and 5.3, 2.83%, and 0.67% for the high-moisture bales, respectively.

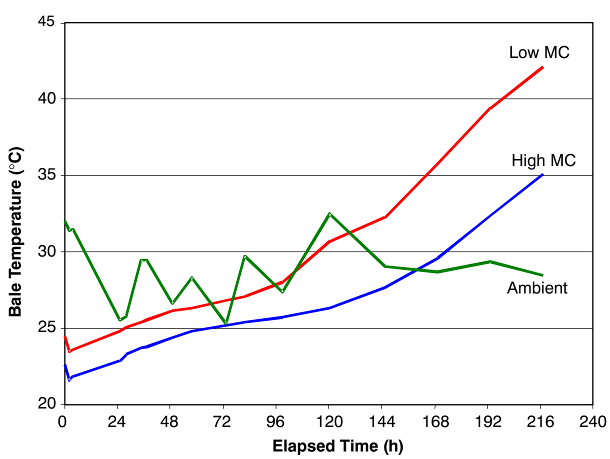

Figure 1. Interior temperature of four second-cutting bales (one LRB and LSB at each moisture level) removed in June 2002 after 348 days in storage. Wet basis moisture was 54.0% and 34.9% for the high and low moisture contents (MC), respectively.

Summary

Compared to individually wrapping bales in plastic film, wrapping in a tube increased productivity by more than 50% while requiring 43% less plastic per unit mass of silage. Wrapping silage bales at moisture contents typically considered too low for preservation in a silo was quite successful. After either 5 or 11 months in storage, losses of DM were less than 7% for all treatments. Average DM loss during storage was 3.5% and 2.3% for the high (~40% to 55% w.b.) and low (~30% to 40% w.b.) moisture treatments, respectively. There were no significant differences in DM loss or nutrient composition between large round and large square bales, bales wrapped individually or in a tube, or high and low moisture ranges except for small inconsistent effects on CP across cuttings. Only the initial moisture content had a significant effect on pH and fermentation acids produced. Low-moisture bales produced significantly lower levels of acetic and lactic acids and had significantly higher pH than bales at higher moisture. However, aerobic stability of the bales as measured by bale heating was acceptable. It took seven or more days for bales to heat above 35°C when they were removed after 348 days in storage. Alfalfa, one of the more difficult forage crops to ensile, can be well preserved as low-moisture silage in wrapped bales.

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Nomenclature

ADF = acid detergent fiber
CP = crude protein
DM = dry matter
LSD = least significant difference
LRB = large round bale or baler
LSB = large square bale or baler
MC = moisture content
NDF = neutral detergent fiber
w.b. = wet basis