New Approaches to Improve Alfalfa Round Bale Storage

The authors are **Kevin J. Shinners, Joshua C. Friede, Matthew F. Digman and David A. Pintens.** Department of Biological Systems Engineering, **Corresponding author:** Kevin J. Shinners, 460 Henry Mall, Madison, WI 53706, 608-263-0756, kjshinne@wisc.edu

Abstract

Modifications to a tube wrapper were made so that breathable film could successfully be applied to a line of round bales. The information gained during the design and implantation of these modifications will inform future design improvements. Considerable condensation of moisture on the outer layers and base of the bales occurred with bales wrapped with stretch plastic film when average initial bale moisture was greater than 19%. This led to spoilage on the bale surface and numerically greater DM losses than unwrapped bales stored indoors. Issues of condensation and surface spoilage were not apparent when bale moisture was between 15 and 19%. These results suggest that even a few percentage points difference in the initial bale moisture can have an important impact of condensation on the interior surface of the wrap and subsequent spoilage on the bale surface. Bales wrapped with breathable film did not exhibit surface spoilage issues compared to those wrapped with stretch plastic film. However, it was difficult to maintain a seal between wrap layers resulting in moisture ingress. Improved sealing at the seams of the breathable film is required to make this a viable bale wrapping option. We also explored the impact that wrap color had on forage quality. The color of stretch plastic film and the number of layers of film did not have a statistical impact on most of the storage metrics considered. Bales wrapped with dark colored wrap exhibited elevated diurnal temperatures and showed evidence browning and caramelization consistent with Maillard reactions on the surface. In the end, the most important variable to promote good conservation of wrapped dry bales is initial bale moisture.

Introduction

Baleage is becoming a more common method of conserving alfalfa round bale value. Producers are adopting this practice because the shorter field drying time reduces weather risks and losses during storage are very low [1,2]. The growth in alfalfa baleage has resulted in greater farmer access to in-line bale wrappers – either through direct or shared ownership, or through dealer rentals. Additionally, wrapping alfalfa bales in an in-line tube is faster and uses considerably less plastic film than individually wrapping [2], so it is a popular choice for economic reasons. Alfalfa producers who make baleage are also interested in being able to conserve dry alfalfa hay by tube wrapping with plastic film allowing them to more fully utilize their equipment investment.

The practice of conserving alfalfa hay as high moisture baleage has been researched and is well understood [1,2]. However, the practice of wrapping dry alfalfa bales to conserve quality has not been the subject of extensive research and producers have found that the practice has not always been successful. For example, when bales are wrapped when moisture between approximately 20% and 25%, water condenses on the interface between the bale and film and localized spoilage occurs. Although the spoilage layer may not very deep, a 5 cm layer of spoilage can represent 10 to 16% of the bale volume depending on diameter. And any spoilage of the outer layer makes the bale look spoiled and perception is important when the hay is marketed. Producers have tried a variety of remedies to this issue, including using different film colors, but no rigorous research has been conducted to quantify the impact of these approaches.

Breathable film (BF) may be a remedy to the issue of moisture condensation causing spoilage. BF can now be applied at baling and is designed to shed precipitation while allowing water vapor inside the bale to escape through microscopic pores [3]. The film allows water vapor, but not liquid water, to pass through a matrix of high-density polyethylene fibers. BF applied to individual bales has been shown to reduce dry matter (DM) loss during storage and conserve the outer layer of the bale, thereby reducing animal rejection [3, 4]. The use of BF on individual bales has been successfully commercialized, but not widely adopted for mainly due to the approximate $6 per bale cost for the wrap above the net wrap cost. Using BF to tube wrap dry alfalfa bales could overcome the concern about added costs because tube wrapping bales with stretch plastic film adds about the same cost as wrapping with BF.

Objectives

The high-level goal of this research was to investigate wrapping dry alfalfa bales with stretch plastic film (SPF) and BF and quantify storage characteristics. Specific project goals and results were:

Project objectives:	Project results:
1. To modify a conventional in-line tube bale wrapper so that breathable film could be applied to dry alfalfa bales.	1. The modified wrapper was able to successfully apply breathable film to round bales of typical size.
2. To compare storage characteristics of dry bales wrapped with three types of film (breathable, and black and white stretch plastics film) with either four or eight layers of plastic film.	2. Neither the plastic film color nor number of layers made a significant difference in storage conservation. Breathable film had less surface spoilage than bales wrapped in plastic film.
3. To compare the storage characteristics of dry bales wrapped at different initial moisture contents.	3. The most important variable to promote good conservation of wrapped dry bales is initial bale moisture. Initial moisture should be in the mid-teens to promote conservation without surface spoilage.

Methodology

Modifications to Apply Breathable Film:

To ensure that the film lays tightly on the bale surface, stretch plastic film (SPF) is passed through a set of rollers called a Pre-Stretch-Unit (PSU). These rollers operate at differential speed which stretches and tensions the film. This stretch and tension, along with the tack material on the films surface, helps to seal the film. BF is essentially paper so it cannot be stretched, and it has no tack layer for sealing. So, two modifications were required to wrap bales in BF – a means to accurately lay the film on the bale surface and a means to seal the seams of the film. Many design iterations were required to develop solutions to these challenges.

Modifications were made first to a H&S Mfg. (Marshfield, WI) model LW1100 wrapper and then final design iterations were applied to a Tubeline (Elmira, ON) model 5500 ECV wrapper. A major challenge involved accurately placing and laying the BF on the bale surface. Because the BF could not be stretched, even a gentle breeze caused it to displace unfavorably as it moved from the PSU rollers to the bale face. This issue was eventually overcome by using elastic cords that ran from one PSU to the opposite PSU (figs. 1 and 2). An additional unpowered roller was placed tangent to the film path and between the PSU rollers and the bale surface to support the film. These modifications restrained the film and helped to correctly place and lay the film on the bales surface. Our original intent was to use only two layers of BF; however, the BF puckered and wrinkled during the rapid advance of wrapper required to create two film layers. It was possible to place three layers without experiencing these puckering issues. Suggestions are provided in Appendix A to modify the wrapper to allow only two layers of wrap.

Dispensers were designed and fabricated to apply tape to the seams to seal the leading and trailing edges of the BF as it was placed on the bale surface. One tape dispenser at the films leading edge was used to place tape on the inside layer of the film. Here the adhesive side was placed outward so that film would adhere to the tape as the film was laid on the bale surface. The tape dispenser on the trailing edge was used to seal the exposed seam by placing tape with the adhesive side toward the bale. Only the tape on the trailing edge was exposed on the BF exterior. Many different types of tape were investigated prior to the experiments, but 96 mm wide by 2 mil thick clear acrylic tape (part number 20CST472C https://www.wraptite.com/) was used in the experiments. An unpowered roller was used to press the tape and the BF together to ensure a good seal at the edges.

With these modifications, BF was successfully used to wrap bales using a tube wrapper (fig. 3). The BF does not have the ability to stretch like plastic film, so it was observed that the BF did not form a good seal at the interface between two bales with large differences in diameter.

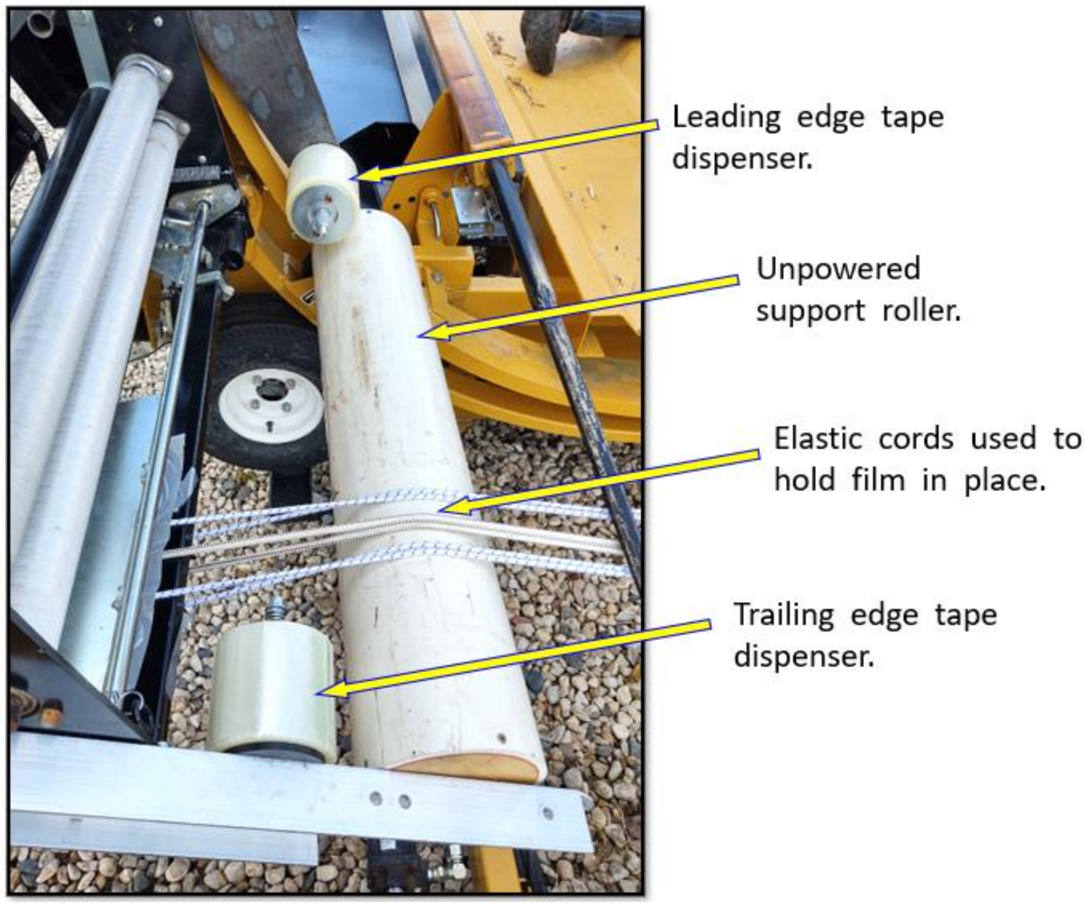


Figure 1. Modifications made to in-line bale wrapper to apply non-stretch breathable film to bale surface. Elastic cords helped place the film on the bale surface without displacement by the wind. Tape was used to seal the seams of the film.

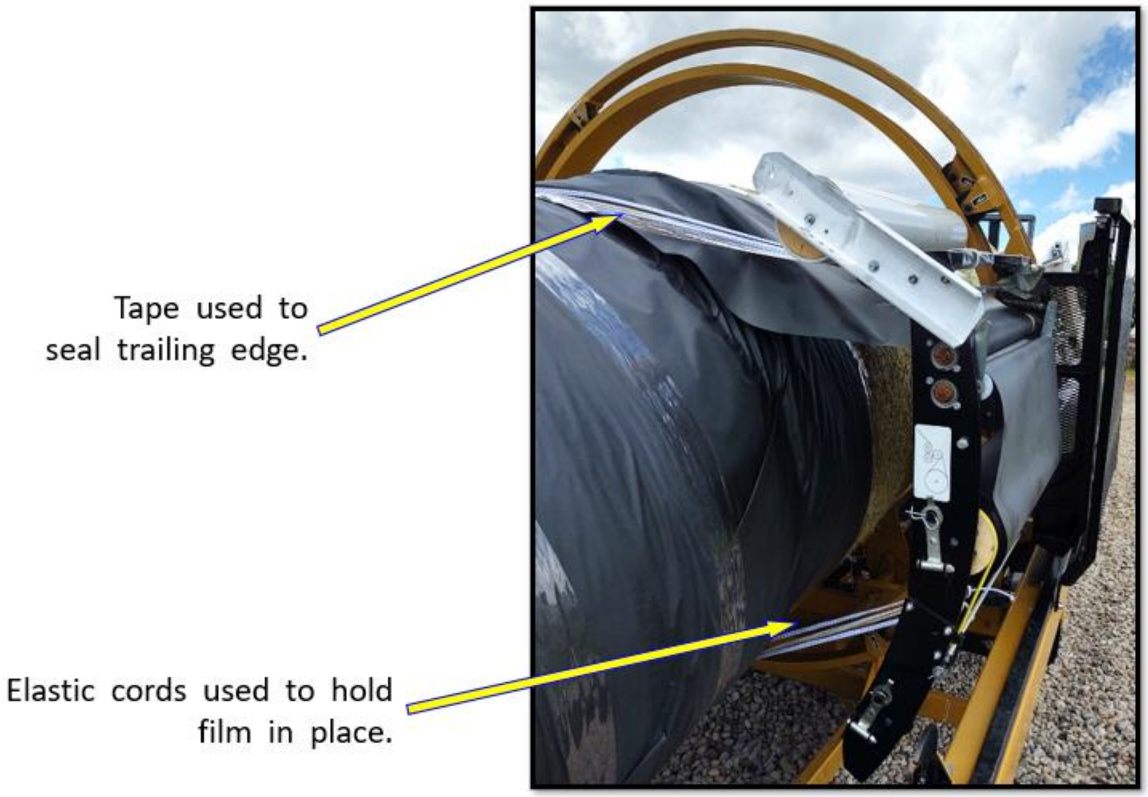


__Figure 2.__ Modifications made to in-line bale wrapper to apply non-stretch breathable film to bale surface. Elastic cords helped place the film on the bale surface without displacement by the wind. Tape was used to seal the seams of the film.

Figure 3. Dry alfalfa bales wrapped in breathable film using the modified bale wrapper. Note spiral wrap of tape at the training edge seam to seal the film.

Quantification of Storage Conservation:

Two experiments were conducted using first or second cutting alfalfa. First cutting alfalfa (2-year-old stand of Pioneer - 55VR08) was cut on 1-Jun. and tedded on 2-Jun. and 3-Jun. before baling on the afternoon of 4-Jun. Bales were wrapped on the morning of 5-Jun. so there was approximately 20 h between baling and wrapping. The bales were made with a Case IH (Racine, WI) model 455 round baler to a target diameter of 140 cm. All bales were weighed on an 1,800 kg capacity platform scale with a resolution of 0.5 kg. The bale diameters were measured by hand to the nearest 2 cm on both sides of the bale in both the horizontal and vertical directions and an average bale diameter calculated. Each bale was subsampled twice with a boring tool of 4 cm diameter to collect samples to determine moisture content and for later analysis of constituent composition. The samples were taken on opposite corners of the bale and bored diagonally to a depth of approximately 50 cm. Samples were combined and the separated into two approximately equal subsamples. One was dried for 24 h at 105°C according to ASABE Standard S358.2 (2013) to determine moisture content and the other for 72 h at 55°C that was used later for compositional analysis.

Seven treatments were investigated: 3-layers of breathable film (BF); 4- or 8-layers of white stretch film (WFW4 or WFW8) (25 micron Agriseal); 4- or 8-layers of black stretch film (BFW4 or BFW8) (25 micron Sunfilm); unwrapped and stored outdoors (UNWO) on a rock pad; and unwrapped and stored inside (UNWI) an open front hay shed. Seven replicate bales of BF and four replicate bales of all remaining treatments were used. The BF bales were placed in one row and the SPF bales were placed in a separate row. Two dry grass bales were used to separate each treatment and to provide a means to transition from 4 to 8 layers and from white to black film. Outdoor stored bales were placed on a rock pad in a separate row. All three rows were placed on a sloped surface with the rows running north to south and in a location where other bales would not shade the rows. Dry grass bales were used at both ends of all rows to encapsulate the bales intended for data collection.

Thermocouple dataloggers were placed at three locations on selected bales. These sensors were placed on the west side of the bale and at the approximate 7, 9 and 11 o-clock positions. Sensors were hand placed in the bales approximately 5 cm from the bale circumference and approximately 12 cm from the bale face. Temperature readings were collected every four hours. Millard reactions which can increase hay ADF and ADIN are relatively minor when hay temperature is less than 35°C [5], so the number of measurements that exceeded 35°C during the storage period was determined.

A similar study was conducted using second cutting alfalfa (3-year-old stand of Dairyland – HybriForce 3430). The field was cut on 2-Jul.; tedded on 3-Jul.; raked on the morning of 6-Jul. and baled that afternoon. Other aspects of harvest were similar that described above. Bales were placed into storage in the early afternoon of 7-Jul. so there was approximately 22 h between baling and wrapping. The procedures for quantifying bale size, weight, moisture content and composition were similar to those described above. Yield was limited so only enough hay was available to make three replicate bales per treatment. The treatments were the same as used in the first experiment except that the indoor treatment was eliminated due to insufficient hay availability. The bales were placed on a gentle slope in a single row on grass sod with the row running north to south. Dry grass bales were used between treatments and at the ends of the rows similar to the first experiment. Thermocouple dataloggers were placed in bales similar to the first experiment.

First and second cutting bales were removed from storage after 148 (Oct. 28th) and 97 days (Oct. 7th) in storage, respectively. Bales were weighed on an 1,800 kg capacity platform scale with a resolution of 0.5 kg. The bale diameters were measured by hand to the nearest 2 cm on both sides of the bale in both the horizontal and vertical directions and an average bale diameter calculated.

Each bale was sampled six times with a boring tool of 4 cm diameter to collect samples to determine moisture and constituent composition. Outer layer and core samples were taken at the approximate 3 and 9 o'clock positions in the approximate middle of the bale. The outer layer sample depth was approximately 20 cm and the core samples were taken from the same hole to a depth of approximately 50 cm. The bale was upended, and two samples were taken from random locations of the base of the bale to a depth of approximately 20 cm. All samples were oven dried for 72 h at 55°C.

To determine the final bale moisture and DM content, the overall volume-adjusted bale moisture content (M_{va}) was calculated by using the bale dimensions described above to calculate the volume of the outer layer, core, and base of the bale and then using:

$$M_{va} = \frac{(M_{ol} \cdot V_{ol} + M_c \cdot V_c + M_b \cdot V_b)}{V_t}$$

where M is wet basis moisture content, V is volume of each bale section, and the subscripts indicate the outer layer (ol), core (c), base (b), and total (t) moisture content or volume.

When bales are removed from storage the outer surfaces were photographed and then subjectively assessed based on color, odor and presence of mold or algae. A detailed moisture profile was produced using conductance-type moisture sensors (model F-2000, Delmhorst Instrument Co., Towaco, NJ). On the vertical faces of the bales, the sensor was inserted to a depth of about 15 cm and measurements were taken at 5, 10, 15, 20, 30, and 50 cm radial distance from the bale circumference and at the approximate center of the bale (fig. 4). Measurements were taken at the two horizontal and two vertical radii on the south face and at the radii offset approximately 45° from these on the north face. Additional moisture sensor data were taken at a depth of 5 cm across the bale circumference to determine the approximate moisture distribution on the outer layer of the bales. Data was taken at 2, 20, 40, 60, 80, 100 and 118 cm from the south edge of the bales. This data was collected approximately every 45° around the bale (fig. 4).

At removal, first cutting bales were sectioned using a large chain saw so that the interior of the bales could be observed (fig. 5). It was observed that differences in the treatments were primarily limited to the outer layer of the bales, so compositional analysis was conducted only of these bore samples (fig. 6). Constituent analysis was conducted by Rock River Labs using conventional NIRS techniques. Bale conservation was quantified by bale temperature, final moisture content, DM loss during storage, and changes in constituent analysis. Treatments were analyzed using a full-factorial experiment design using the Standard Least Squares option in the Fit Model platform of JMP Pro Version 13.1 (SAS Institute Inc., Cary, NC, USA). Statistical differences of means were determined using Tukey's test at 5% significance level.

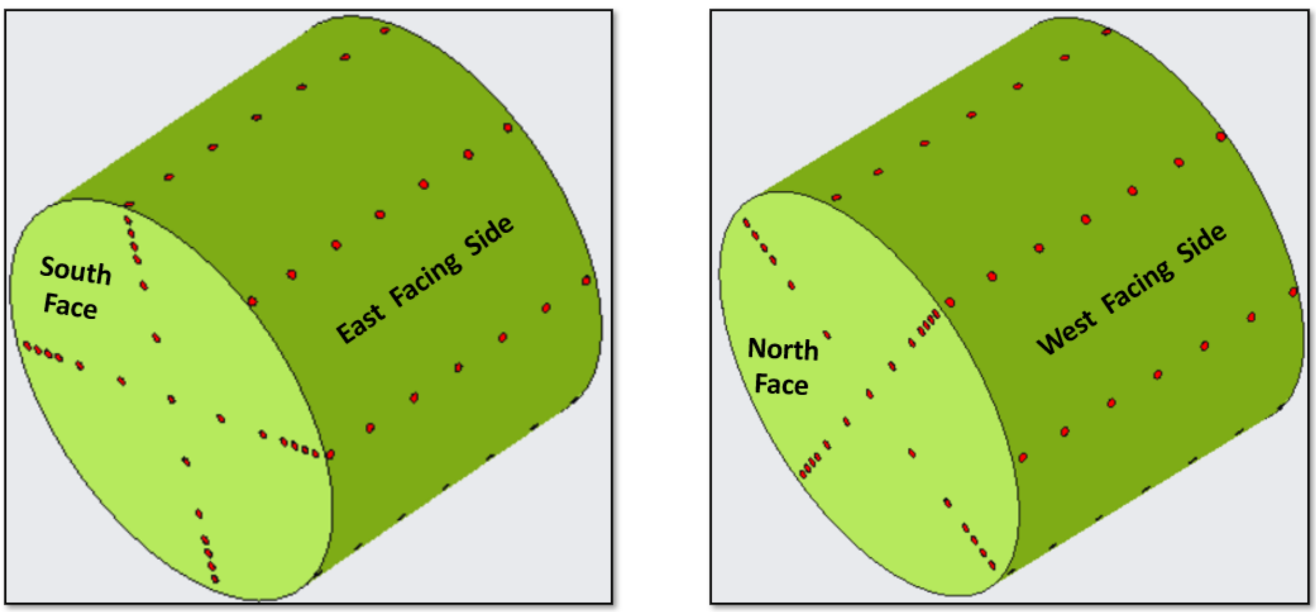


Figure 4. Locations where moisture sensor data was collected. Data from the vertical faces was collected parallel to the bale's longitudinal axis to a depth of approximately 15 cm. Data on the circumference was collected radially to a depth of approximately 5 cm.

Figure 5. Sectioning bales to observe the hay conservation inside the bale.

Results and Discussion

First Cutting

Total precipitation during the 148 day storage period 57 cm. Initial moisture content going into storage was not significantly different across treatments (table 1). Average initial moisture was 19.2% (w.b.) with a range from 15.8% to 23.0%. At removal from storage, the moisture content of the bore samples taken from 20 to 50 cm depth (i.e., from the bale core) were significantly greater for the WFW8 and BFW8 bales than for BF, UNWO or UNWI bales (table 1). However, core moisture contents across most treatments were generally within the range where spoilage would be considered minimal. The cores of sectioned bales were observed to be well conserved across all treatments and there no observed evidence of spoilage (fig. 6).

The moisture content of bore samples from the base of the WFW and BFW bales were greater than 25% (w.b.) (table 1) and a thin layer of spoilage was observed (fig. 7 and 8). During the heat of the day, water in the bales can vaporize. During the cool nights, water vapor can condense on the inside surface of the film and eventually drain to the bottom of the bale. This is likely why bales wrapped in SPF had high moisture and spoilage in the base of the bales.

Table 1. Moisture contents and dry matter loss of first cutting alfalfa bales wrapped in three different materials and stored for 148 days. Precipitation during storage period was 57 cm.

Treatment[a]	Film layers	Into storage moisture content (% w.b.)	Moisture content at removal from storage (% w.b.)				Dry matter loss (% of DM)
			Outer layer	Core	Base	Volume adjusted	
Unwrapped - Indoors		19.3a	16.5c	16.7c	23.7b	16.9b	4.4a
Unwrapped - Outdoors		20.2a	19.4bc	17.3c	37.9b	20.0ab	6.9a
Breathable Film	3	18.7a	17.7c	17.3c	58.9a	21.6a	3.0a
White Film	4	18.5a	25.2ab	20.6abc	30.2b	23.2a	7.7a
White Film	8	20.2a	25.9a	22.4a	28.6b	24.3a	5.9a
Black Film	4	17.7a	23.9ab	17.7bc	36.0b	21.7a	7.7a
Black Film	8	20.2a	25.3ab	21.4ab	35.0b	24.7a	7.0a
SEM [b]		0.84	1.38	0.90	2.96	0.95	1.29
P-values [c]		0.2939	< 0.0001	0.0002	< 0.0001	< 0.0001	0.2901

[a] All film wrapped treatments and the unwrapped bales were stored outdoors on a rock pad.

[b] Standard error of the mean.

[c] Within each column, lower case markers indicate significant differences at $P < 0.05$ using Tukey's comparisons.

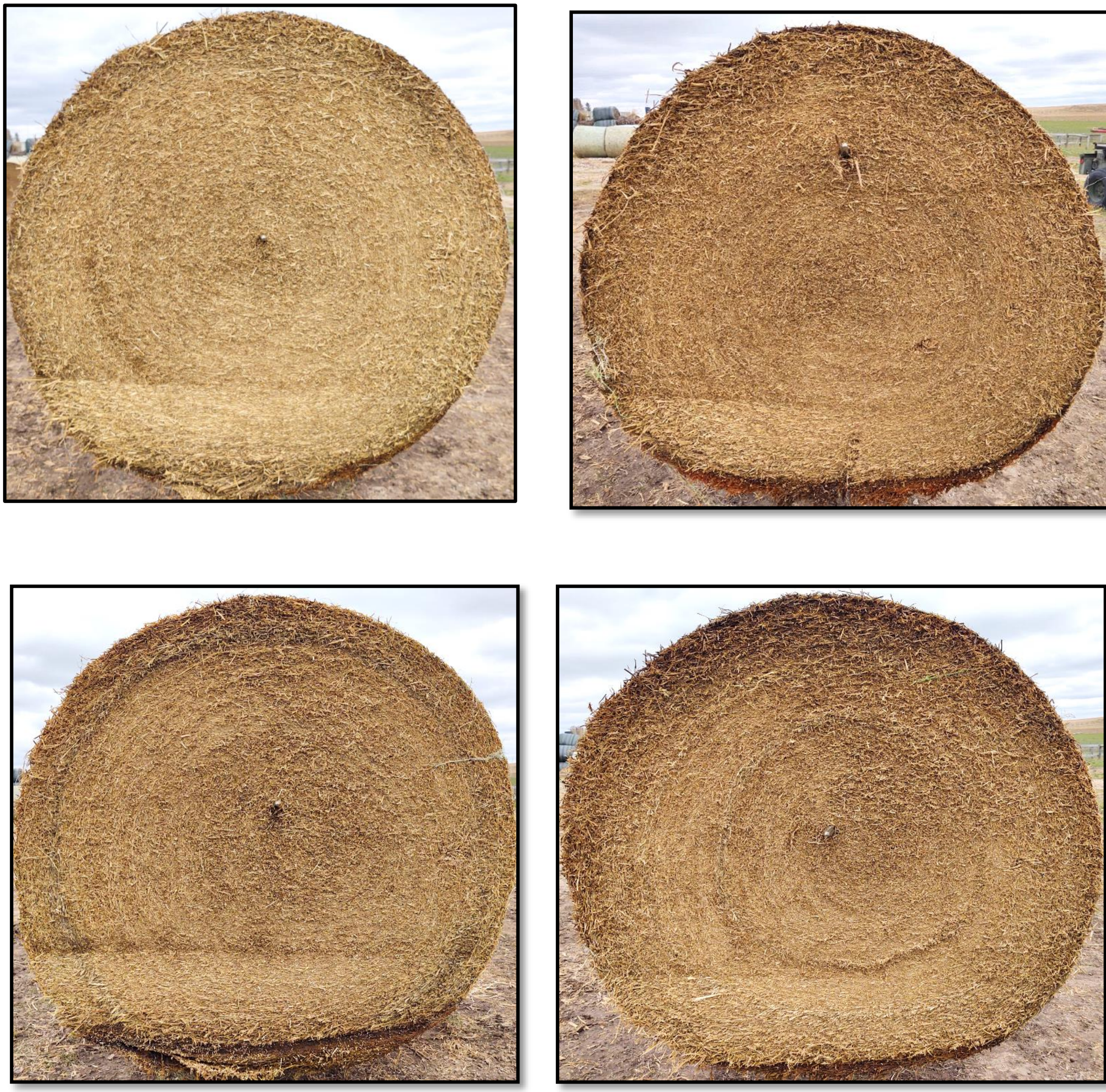


Figure 6. Sectioned first cutting bales from upper left clockwise stored outdoors (UNWO), wrapped in four layers of white plastic film (WFW4), wrapped in four layers of black plastic film (BFW4), and wrapped in breathable film (BF). Left side was exposed to the west. Note thin layer of wet, spoiled hay on bottom of wrapped bales.

Figure 7. Observed surface mold and localized spoilage on the bottom of first cutting bales wrapped in four layers of white stretch plastic film (WFW4). Example on the left was observed to have the least surface spoilage and, on the right, the most spoilage of first cutting bales.

Figure 8. Observed surface mold and localized spoilage on the bottom of first cutting bales wrapped in eight layers of black stretch plastic film (BFW8). Example on the left was observed to have the least surface spoilage and, on the right, the most spoilage of first cutting bales.

The bales wrapped in BF had very high moisture content in the base (table 1). The BF likely allows some diurnal movement of water vapor in and out of the bale. The tape used to seal the BF likely prevented water vapor from escaping through the film's microscopic pores at the spiral sections of the film's seams. This created an area where water could condense when temperatures cooled at night. This condensed water could then drain down to the base of the bales. A distinct stripe of discolored hay was visible on the bale surface where the tape spiraled around the bale at the seams (fig. 9). It is also possible that the tape did not completely seal the seams, so rainwater could have entered the film at some locations at the seams. Whatever the root cause, these bales had a 3 to 5 cm spoiled layer on the bottom of the bale.

At removal from storage, the moisture content of the bore samples taken from outer 20 cm were significantly greater for the SPF treatments than for BF, UNWO or UNWI bales (table 1). There was no significant difference in the outer layer moisture content between the four SPF treatments. Condensation on the bale surface and patches of mold were observed on the SPF wrapped bales when the film was removed (fig. 10). Data collected using the conductance moisture sensor at 56 locations around the periphery of the bales (fig. 4) showed that the estimated moisture content at 5 cm depth was greater for the SPF bales than BF bales (table 2). There was a trend for moisture to be greater in SPF bales wrapped with four layers compared to eight layers (table 2).

A computer program was developed that created a spatial moisture distribution image using the 50 moisture sensor data points collected at a depth of 20 cm from the bale vertical faces. Although 50 data points used to create these images represent a relatively small fraction of the bale volume, they do provide a more complete estimate of the bale's moisture distribution than the oven dried bore samples. Data was taken from all bales and then averaged to create a single image representing each treatment. The image of the UNWI bales showed that moisture content was uniformly distributed and well below the level where spoilage would be a concern (fig. B1). The moisture distribution images of the UNWO bales and those wrapped in BF were similar (fig. B2). Less than 5% of the image area indicates hay moisture greater than 22% (w.b.). More than 80% of the image area of the SPF wrapped eight layers of either color film and four layers of black film indicated moisture was greater than 22% (fig. B3 and B4). The moisture distribution images from the two SPF treatments wrapped with four layers of film show a distinct wet layer around the periphery of the bale (figs. B3 and B4). This phenomenon was not exhibited in the BF bales (fig. B2) supporting the conclusion that BF minimized condensation on the film interior.

Figure 9. Locations on the bale surface where tape used to seal the breathable film seams resulted in discoloration likely due to water condensation.

Figure 10. Observed surface mold and localized spoilage on the sides of first cutting bales wrapped in eight layers of white (WFW8 – left) and black (BFW8 – right) stretch plastic film.

Table 2. Moisture contents for first cutting alfalfa bales as measured with conductance moisture sensor at 5 cm radial distance from the bale surface at various angular positions.

Angular position from top dead center[a]	Average moisture sensor data[b, c] (% w.b.)						
	Unwrapped	Unwrapped	Breathable	White Film		Black Film	
	Indoors	Outdoors	Film	4 Layers	8 Layers	4 Layers	8 Layers
0	12.0	19.1	24.2	40.0	37.4	40.0	37.3
45	11.4	20.6	20.2	39.8	37.7	40.0	33.4
90	11.3	23.4	13.9	35.7	26.7	37.5	35.6
135	11.3	29.3	15.9	32.9	26.5	36.7	32.8
180	30.9	37.4	40.0	40.0	38.7	40.0	39.1
225	11.4	29.5	11.8	32.9	20.5	25.1	22.3
270	11.5	20.4	11.4	36.2	26.9	34.4	28.2
315	11.9	15.1	17.2	39.8	34.9	39.6	34.4
Treatment average	14.0	24.4	19.3	37.2	31.2	36.6	32.9

[a] For bales stored outdoors, measurements at 45, 90 and 135 degrees were on the east side of the bale and measurements 225, 270 and 315 degrees on the west side of the bale.

[b] Maximum sensor output was 40% (w.b.) moisture content.

[c] Each value is an average from the four replicates bales on all treatments except the breathable film which was an average from seven replicate bales.

There were no statistical differences in DM loss over the storage period between treatments (table 1). The numerically lowest DM loss occurred in the UNWI and BF bales. Even though wrapping in SPF prevented 57 cm of precipitation from reaching the bales, storage losses were for bales wrapped in SPF were similar to those of UNWO bales. The bore samples and moisture distribution images showed that the SPF trapped moisture vapor in the bales which likely contributed to the loss of DM during storage. The bore samples and moisture distribution images showed that the BF bales allowed water vapor to leave that bale which likely contributed to the lower DM loss.

Temperature in the bale were measured at three locations at a depth of approximately 12 cm on the west facing side of the bales. Bales wrapped in BF (which was black in color) and the BFW had greater maximum temperatures than other treatments and the diurnal temperature fluctuations were greater (fig. 11). The number of sampling events where the temperature was greater than 35°C was greater for bales wrapped in BF and BFW (table 3). It was observed that these bales had evidence of browning consistent with Maillard reactions on the surface (fig. 12) and there was a distinct caramelized odor at removal from storage. This phenomenon appeared to the limited to approximately 2 to 3 cm depth.

There were no detectable differences between treatments across all compositional metrics analyzed from the bore samples of the outer layer of the bales (table 4). After storage there were small increases in the mass fractions of fiber (ADF, NDF), lignin (ADIL) and ash compared to the initial into storage values (table 4). This was most likely due to loss of digestible DM (table 1). Although there was observed browning consistent with Maillard reactions on the BF and BFW bales (fig. 12), this did not affect the nutrient composition compared to other treatments. This was likely due to the thin 2 to 3 cm layer affected compared to the overall volume of the sample from the outer layer that was 20 cm deep. The fiber and lignin content of the outer layer was numerically greater for the UNWO bales stored outdoors, but these differences were not statistically significant.

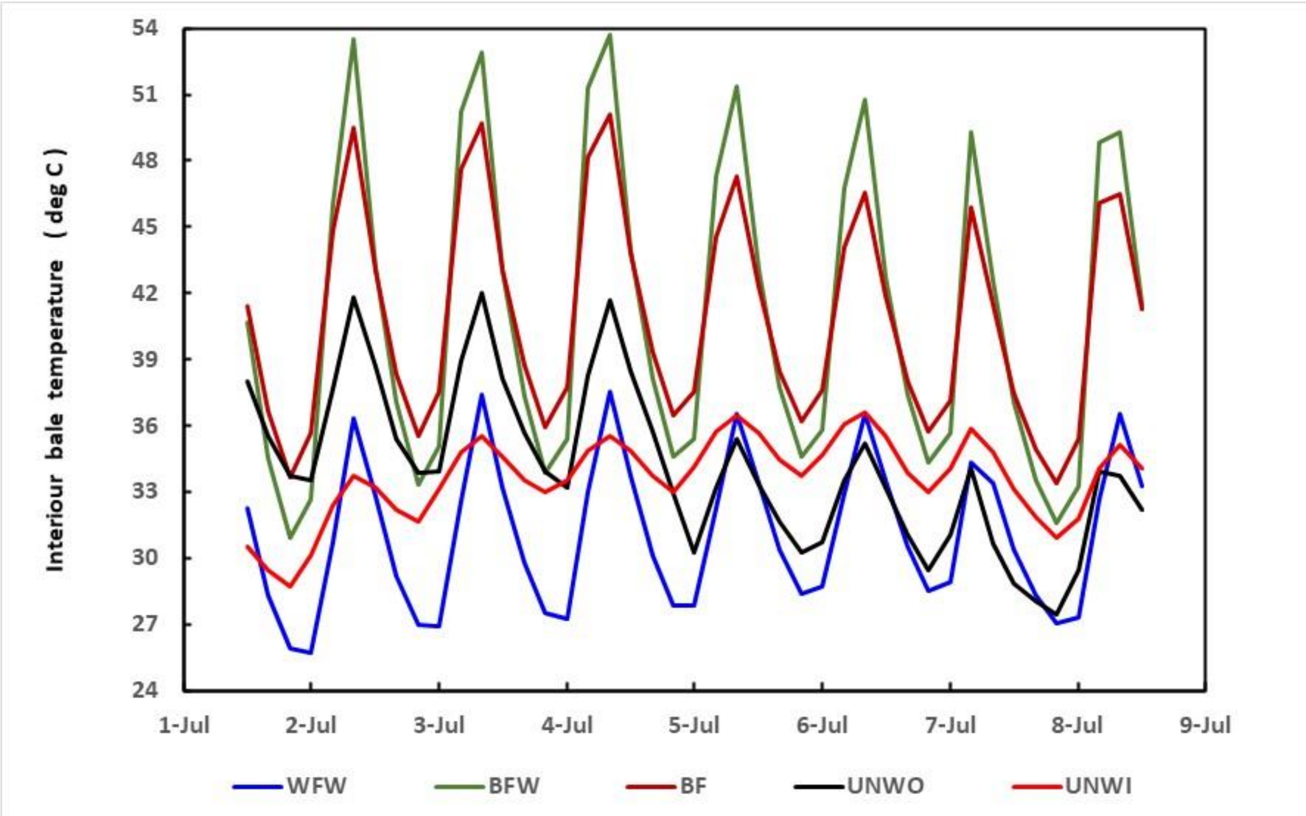


Figure 11. Diurnal temperature over one week period of first cutting bales stored indoors without wrap (UNWI), stored outdoors without wrap (UNWO), wrapped in white or black stretch plastic film (WFW or BFW) or wrapped in breathable film (BF). Temperature was measured every four hours at depth of 12 cm in the top quadrant on the west side of the bale.

Figure 12. Surface of bale wrapped in four layers of black stretch plastic film (BFW4) showing browning consistent with Maillard reactions due to elevated temperature under film (left). Right photo shows the relatively thin layer of browning.

Table 3. Number of sampling periods when measured temperature in first cutting bales was greater than 35°C at one of three sampling locations on the bale.

		Sampling periods greater than 35°C		
		Angular position from top dead center[b]		
Treatment[a]	Film layers	315 deg	270 deg	225 deg
Unwrapped - Indoors		10	1	0
Unwrapped - Outdoors		34	43	0
Breathable Film	3	216	133	45
White Film	4	63	3	0
White Film	8	7	7	10
Black Film	4	282	137	35
Black Film	8	223	184	149

[a] All film wrapped treatments and the unwrapped bales were stored outdoors on a rock pad.

[b] All thermocouples were located on the west side of the bales. Thermocouples were at approximately 10:30, 9 and 7:30 clock positions for 315, 270 and 225 degree angular positions, respectively.

Table 4. Forage nutrient composition for first cutting alfalfa bales wrapped in different materials and layers of film.

		Composition[b] (% of DM)					
Treatment[a]	Layers	CP	ADF	aNDF	ADL	NSC	Ash
Into Storage		14.2	44.8	54.2	10.4	9.4	7.8
Unwrapped - Indoors		14.2a	46.0a	55.5a	10.9a	8.2a	8.0a
Unwrapped - Outdoors		14.3a	49.4a	59.6a	12.2a	5.9a	7.9a
Breathable Film	3	14.1a	48.0a	57.9a	11.4a	6.8a	8.0a
White Film	4	14.5a	48.8a	58.1a	11.9a	6.4a	8.7a
White Film	8	14.0a	46.4a	56.2a	10.9a	8.5a	8.6a
Black Film	4	14.0a	48.5a	58.2a	11.9a	6.9a	8.2a
Black Film	8	14.5a	48.3a	57.6a	11.8a	6.5a	9.2a
SEM [c]		0.30	1.21	1.44	0.42	0.99	0.33
P-values [d]		0.8379	0.4131	0.5359	0.1868	0.5181	0.0632

[a] All film wrapped treatments and the unwrapped bales were stored outdoors on a rock pad.

[b] Crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), non-structural carbohydrate (NSC).

[c] Standard error of the mean

[d] Within each column, lower case markers indicate significant differences at P < 0.05 using Tukey's comparisons.

Second Cutting

Total precipitation during the 97 day storage period 44 cm. Initial moisture content going into storage was not significantly different across treatments (table 5). Average initial moisture was 16.0% (w.b.) with a range from 12.9% to 19.2%. At removal from storage, the moisture content of the bore samples taken from 20 to 50 cm depth (i.e., from the bale core) were similar across all treatments (table 5). The core moisture contents across all treatments were well below the range where spoilage would be considered an issue and there was no visual evidence of spoilage.

The moisture content of bore samples from the base of the bales that were wrapped in SPF were similar and well below the range where spoilage would be considered an issue (table 5). This result was quite different in first cutting bales that were at greater initial moisture content. There was little to no evidence of spoilage on the base of second cutting bales wrapped with SPF (fig. 13).

The bales wrapped in BF had very high moisture content in the base similar to first cutting (table 5). When the wrap was removed, we observed that the tape did not seal the seams as well in second cutting as it did in first cutting, which likely caused rainwater collect in the bottom of the bale. However, the wet layer was only 3 to 5 cm thick, so spoilage was localized (fig. 14). The UNWO bales also had very high moisture content in the base (table 5). First cutting bales were stored on a rock pad while second cutting bales were stored on sod. Water draining from the round surface of the UNWO bales might have wicked into the bale where they contacted the soil.

There were some statistical differences in moisture of the bore samples taken from outer 20 cm but the differences did not have practical significance because they were well below the range where spoilage would be considered an issue (table 5). Whereas first cutting SPF bales had greater moisture in the outer layer and showed evidence of spoilage, there was little to no evidence of spoilage in second cutting bales. Data collected using the conductance moisture sensor at 56 locations around the periphery of the bales (fig. 4) showed that the estimated moisture content at 5 cm depth was similar for the SPF and BF bales and that there were few differences between the BF, WFW or BFW bales (table 6). The UNWO bales exhibited greater moisture in the outer layer than the BF, WFW or BFW bales (table 6).

The average estimated circumferential moisture content using the moisture sensor was 30.3% and 17.1% for first and second cutting bales, respectively (tables 2 and 6). Average moisture going into storage was 19.2% (w.b.) with a range from 15.8% to 23.0% for first cutting bales and 16.0% (w.b.) with a range from 12.9% to 19.2% for second cutting bales. Although these differences were not great, the differences in estimated circumferential moisture and the observed differences in surface spoilage suggest that even a few percentage points difference in the initial bale moisture can have an important impact of condensation on the interior surface of the wrap and subsequent spoilage on the bale surface.

Table 5. Moisture contents and dry matter loss of second cutting alfalfa bales wrapped in three different materials and stored for 98 days.

Treatment[a]	Film layers	Into storage moisture content (% w.b.)	Moisture content at removal from storage (% w.b.)				Dry matter loss (% of DM)
			Outer layer	Core	Base	Volume adjusted	
Unwrapped - Outdoors		16.4a	16.7a	14.8a	60.9a	21.1a	8.2a
Breathable Film	3	17.2a	13.9ab	14.3a	43.9b	19.8a	3.3b
White Film	4	15.9a	13.8ab	13.1a	15.2c	13.7bc	2.3b
White Film	8	17.7a	17.2a	15.2a	16.8c	16.0b	3.7b
Black Film	4	13.9a	11.5b	11.8a	15.3c	12.2c	2.7b
Black Film	8	14.8a	12.2b	12.8a	15.8c	13.1bc	3.7b
SEM [b]		1.06	0.83	0.78	1.73	0.77	0.71
P-values [c]		0.1704	0.0021	0.0647	< 0.0001	< 0.0001	0.0008

[a] All film wrapped treatments and the unwrapped bales were stored outdoors on grass sod.
[b] Standard error of the mean.
[c] Within each column, lower case markers indicate significant differences at P < 0.05 using Tukey's comparisons.

Figure 13. Base of second cutting bales wrapped in four layers of black plastic film (BFW4 – left) and white plastic film (WFW4 – right). Example on the left was observed to have the least spoilage and, on the right, the most spoilage of second cutting bales.

Figure 14. Base of second cutting bales wrapped in breathable film (BF – left). Thin layer of very wet hay in the base of these bales indicated that spoilage was localized to a layer 3 to 5 cm thick.

Table 6. Moisture contents for second cutting alfalfa bales as measured with conductance moisture sensor at 5 cm radial distance from the bale surface at various angular positions.

Angular position from top dead center[a]	Average moisture sensor data[b, c] (% w.b.)					
	Unwrapped	Breathable	White Film		Black Film	
	Outdoors	Film	4 Layers	8 Layers	4 Layers	8 Layers
0	22.3	22.5	25.5	29.0	22.0	25.1
45	23.1	17.2	21.0	24.0	17.3	19.7
90	19.7	15.2	13.8	18.7	15.3	13.3
135	21.1	15.2	12.9	17.3	12.8	12.0
180	39.7	40.0	16.7	21.8	16.4	19.0
225	25.8	14.9	11.5	15.6	9.2	8.7
270	22.8	13.4	12.2	16.3	8.7	9.6
315	23.9	17.6	16.7	22.5	11.1	11.8
Treatment average	24.8	19.5	16.3	20.7	14.1	14.9

[a] For bales stored outdoors, measurements at 45, 90 and 135 degrees were on the east side of the bale and measurements 225, 270 and 315 degrees on the west side of the bale.

[b] Maximum sensor output was 40% (w.b.) moisture content.

[c] Each value is an average from the three replicates bales on all treatments.

The moisture distribution images of the UNWO showed greater moisture, especially in the outer layers (fig. C1). The moisture distribution images for the BF showed elevated moisture in the bottom of the bale, but most of the image shows hay less than 20% (w.b.) moisture. The moisture distribution images from bales wrapped in SPF all exhibited very uniform moisture distribution with no fraction of the bales greater than 22% (w.b.) moisture (figs. C2 and C3). The moisture distribution images were similar for both film colors and number of layers of wrap.

No statistical differences were detected in DM loss over the storage period between the BF or SPF treatments (table 5). In all cases, the losses were less than 4% of DM. The type of film, film color, or number of layers of wrap had no measurable impact on DM losses. The UNWO bales had statistically greater DM losses compared to BF or SPF bales. Although there were not large differences in moisture content between treatments, it is important to consider that the moisture data collected at removal from storage does not reflect the changes in moisture that can take place in unwrapped bales over the storage duration as rainfall events occur.

Temperature in the bales were measured at three locations at a depth of approximately 12 cm on the west facing side of the bales. Bales wrapped in BF (which was black in color) and the BFW again had greater maximum temperatures than other treatments and the diurnal temperature fluctuations were greater (fig. 15). The number of sampling events where the temperature was greater than 35°C was greater for bales wrapped in dark colored BF and BFW (table 7). It was again observed that these bales had browning consistent with Maillard reactions on the surface and there was a distinct caramelized odor. This phenomenon appeared to be limited to approximately 2 to 4 cm depth.

There were small significant differences between treatments across some compositional metrics analyzed from the bore samples of the outer layer of the bales (table 8). After storage there were small increases in the mass fractions of fiber (ADF, NDF), lignin (ADIL) and ash compared to the initial into storage values (table 8). The compositional changes were small, and this reflects that the that loss of digestible DM was small for the wrapped bales (table 5). Although not statistically significant, the UNWO bales had numerically greater fiber, lignin and ash content, and lower NSC content which was likely due to the greater DM losses in these bales.

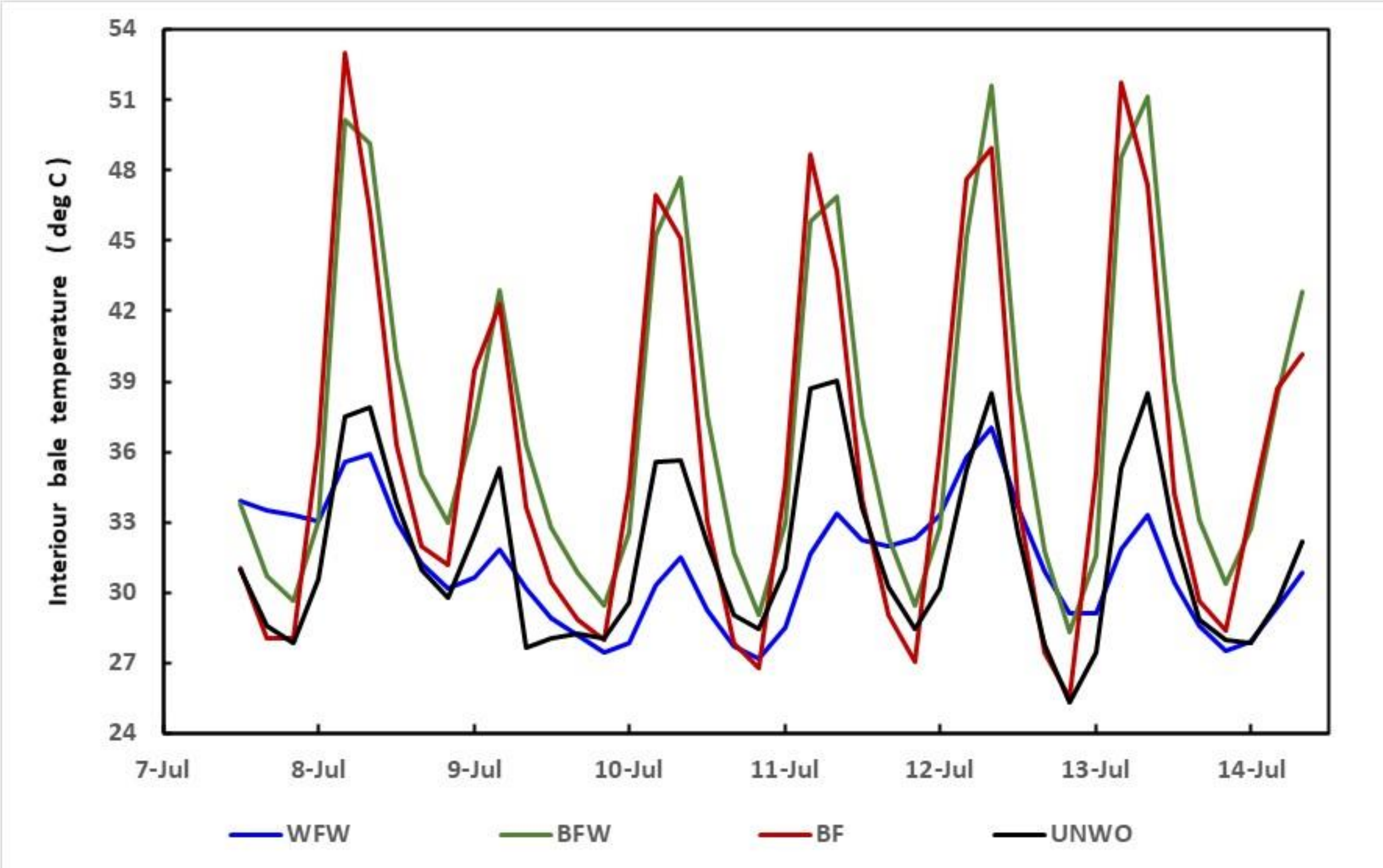


Figure 15. Diurnal temperature over one-week period for bales stored outdoors without wrap (UNWO), wrapped in white or black stretch plastic film (WFW or BFW) or wrapped in breathable film (BF). Temperature was measured every four hours at depth of 12 cm in the top quadrant on the west side of the bale in four-hour intervals.

Table 7. Number of sampling periods when measured temperature in second cutting bales was greater than 35°C at one of three sampling locations on the bale.

		Sampling periods greater than 35°C		
		Angular position from top dead center[b]		
Treatment[a]	Film layers	315 deg	270 deg	225 deg
Unwrapped - Outdoors		39	27	3
Breathable Film	3	114	60	34
White Film	4	44	17	3
White Film	8	6	2	1
Black Film	4	110	37	7
Black Film	8	121	79	22

[a] All film wrapped treatments and the unwrapped bales were stored outdoors on a rock pad.
[b] All thermocouples were located on the west side of the bales. Thermocouples were at approximately 10:30, 9 and 7:30 clock positions for 315, 270 and 225 degree angular positions, respectively.

Table 8. Forage nutrient composition for second cutting alfalfa bales wrapped in different materials and layers of film.

		Composition[b] (% of DM)					
Treatment[a]	Layers	CP	ADF	aNDF	ADL	NSC	Ash
Into Storage		18.0	37.9	45.1	9.0	10.9	11.4
Unwrapped - Outdoors		18.6a	39.1a	46.3a	9.3a	9.6a	12.1a
Breathable Film	3	20.0a	34.6b	42.2b	8.3a	11.2a	11.0ab
White Film	4	17.9a	37.7ab	45.4ab	8.9a	11.0a	11.0a
White Film	8	19.2a	36.9ab	43.5ab	9.0a	10.7a	12.7a
Black Film	4	18.3a	38.7a	45.4a	9.3a	10.2a	11.4ab
Black Film	8	18.0a	38.5a	46.4a	9.2a	10.4a	10.1b
SEM [c]		0.46	0.75	0.66	0.25	0.34	0.37
P-values [d]		0.0566	0.0117	0.0045	0.0955	0.0597	0.0057

[a] All film wrapped treatments and the unwrapped bales were stored outdoors on a rock pad.
[b] Crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), non-structural carbohydrate (NSC).
[c] Standard error of the mean
[d] Within each column, lower case markers indicate significant differences at P < 0.05 using Tukey's comparisons.

Conclusions

Breathable film was successfully applied to a line of round bales. Bales wrapped in this material exhibited some improved storage characteristics, particularly less condensation on the bale surface. However, work is needed to implement design changes to the wrapper to make this an option for wrapping bales in practice. Changes to the BF itself are also needed to seal the seams without need for applying tape. Regarding bales wrapped with stretch plastic film, the most important variable to promote good conservation of wrapped dry bales was the initial bale moisture. The color of stretch plastic film and the number of layers of film did not have a statistical impact on most of the storage metrics considered. Bales wrapped with dark colored wrap exhibited elevated diurnal temperatures and showed browning and caramelization on the surface consistent with Maillard reactions. Condensation of moisture on the outer layers and base of the bales occurred with bales wrapped with stretch plastic film, especially when the bale moisture content was greater than 19% (w.b.). Achieving bale moisture less than this value can be difficult in humid climates. If weather conditions make it unlikely that moistures less than 19% (w.b.) can be attained, producers may want to consider wrapping at greater moisture to promote fermentation as baleage.

References:

1. Coblentz, W. K., & Akins, M. S. (2018). Silage review: Recent advances and future technologies for baled silages. Journal of Dairy Science, 101(5), 4075-4092.
2. Shinners, K.J., B.M. Huenink, R.E. Muck and K.A. Albrecht. 2009. Storage characteristics of large round and square alfalfa bales: low-moisture silage bales. Transactions of ASABE. 52(2): 401-407.
3. Shinners, K.J., G.C. Boettcher, D.M. Schaefer, and A.M. Troutman. 2013. Cattle preference for hay from round bales with different wrap-types. Professional Animal Scientist. 29:665-670.
4. Reiter, A. S., Sheaffer, C. C., Wells, M. S., Grev, A. M., Hathaway, M. A., Lazarus, B., & Martinson, K. (2020). Effect of alfalfa cultivar and bale wrap type on dry matter and forage quality of large round bales in outdoor storage. Applied Engineering in Agriculture, 36(6): 975-982.
5. Rotz, C.A.; & Muck. R.E. (1994). Changes in forage quality during harvest and storage. In: Fahey Jr., G.C.; Collins, M.; Mertens, D.R.; Moser, L.E. (ED). Forage quality, evaluation and utilization. Madison: ASA; CSSA; SSSA, p.828-868.

APPENDIX A

Suggestions for Improving Tube Wrapper for Applying Breathable Film

Breathable film (BF) is essentially a paper product, and this has no ability to stretch and conform like stretch plastic film (SPF). Because of this, even a gentle breeze caused the film to displace unfavorably as it was dispensed from the rolls on the wrapping hoop to the bale surface. The ratio of hoop speed to forward displacement of the wrapper dictates the number of layers of wrap applied. Film puckering on the bale surface occurred when it was attempted to place only two layers of BF on the bales. Suggestions for design changes to the wrapper would include:

- Developing a system that restrains the BF from the roll on the hoop all the way to the bale. In this work elastic cords were used, but other alternatives should be explored. These might include a series of rollers or ramps.

- The BF is not as flexible as SPF. Currently the rolls of film are placed parallel to the bale surface. When the forward displacement of the wrapper is small (i.e., more layers applied) the lack of flexibility is not an issue. However, for economic reasons it may be desired to use only two layers of BF. Skewing the BF roll at an angle away from parallel to the bale surface might allow application of two layers without the puckering issues observed.

- Using tape to seal the seams of the BF is not an acceptable solution in practice. Currently available BF does not have an adhesive at the edges to seal the seams. For BF to be a viable material for wrapping a line of bales, adhesive needs to be available on the edges of the film. Rollers on the wrapper hoop that press o the seam should be considered to ensure that the adhesive edges are properly sealed.

APPENDIX B

Moisture Distribution Images

First Cutting Alfalfa Bales

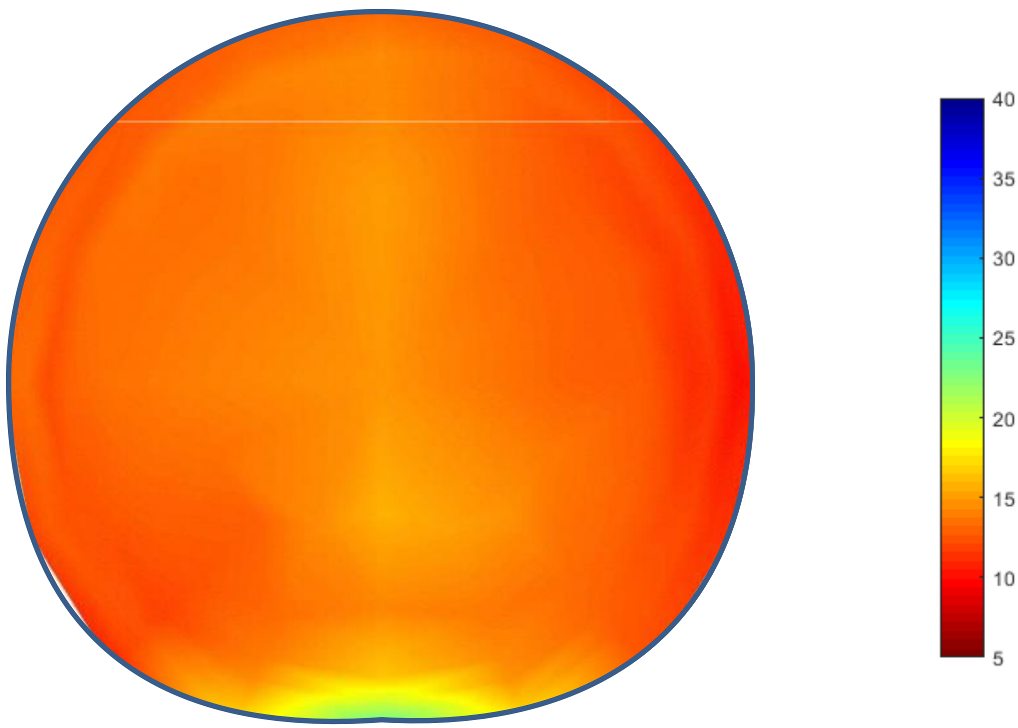


Figure B1. Moisture content (% w.b.) distribution for 1st cutting bales stored in open front hay shed. Maps generated by collecting moisture content estimates using a conductance moisture sensor at locations on the bale north and south faces (see fig. 4.). Scale located to right of figure.

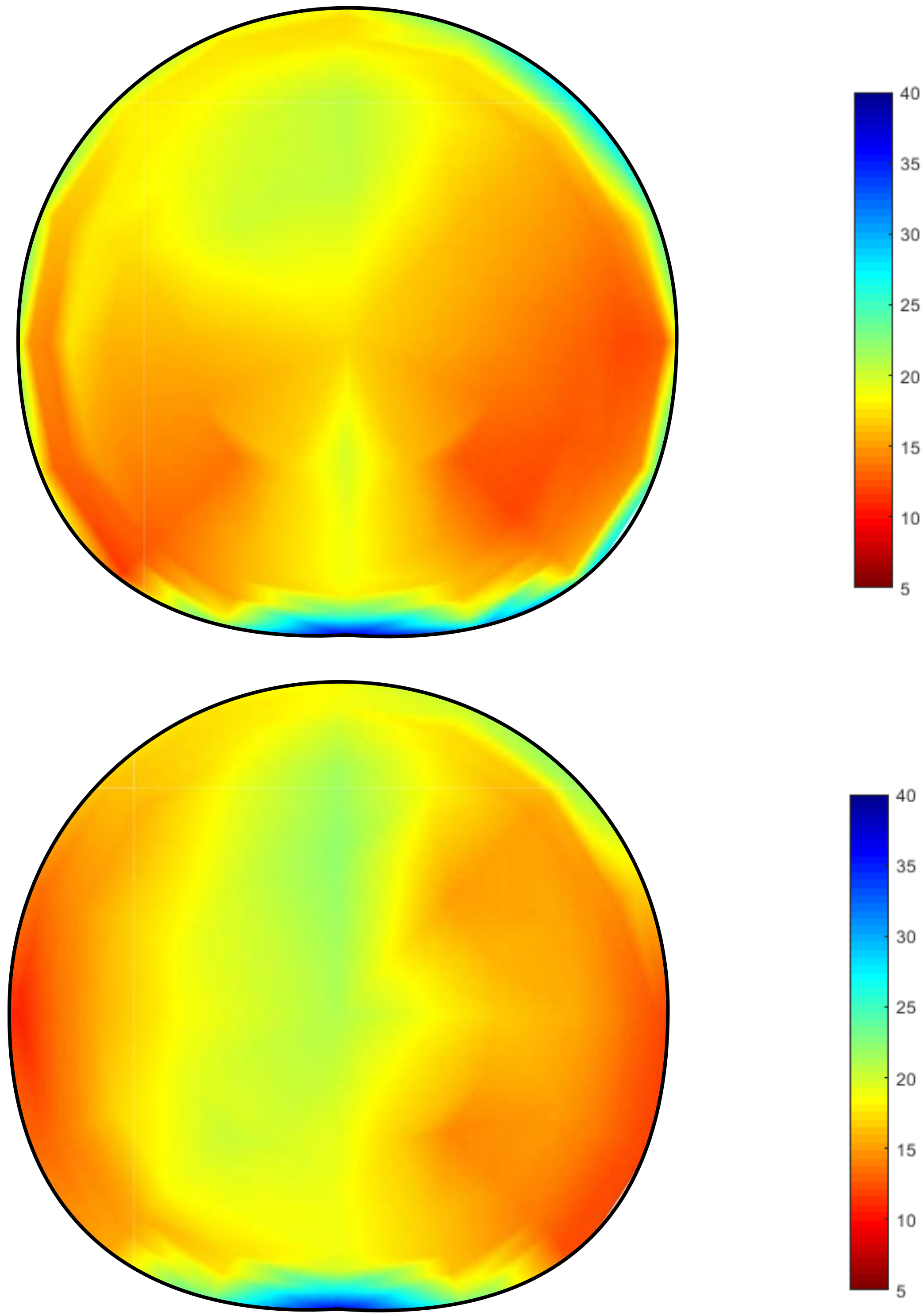


__Figure B2.__ Moisture content (% w.b.) distribution for 1st cutting bales stored outdoors unwrapped (top) or wrapped in breathable film (bottom). Maps generated by collecting moisture content estimates using a conductance moisture sensor at locations on the bale north and south faces (see fig. 4.). Scale located to right of figure.

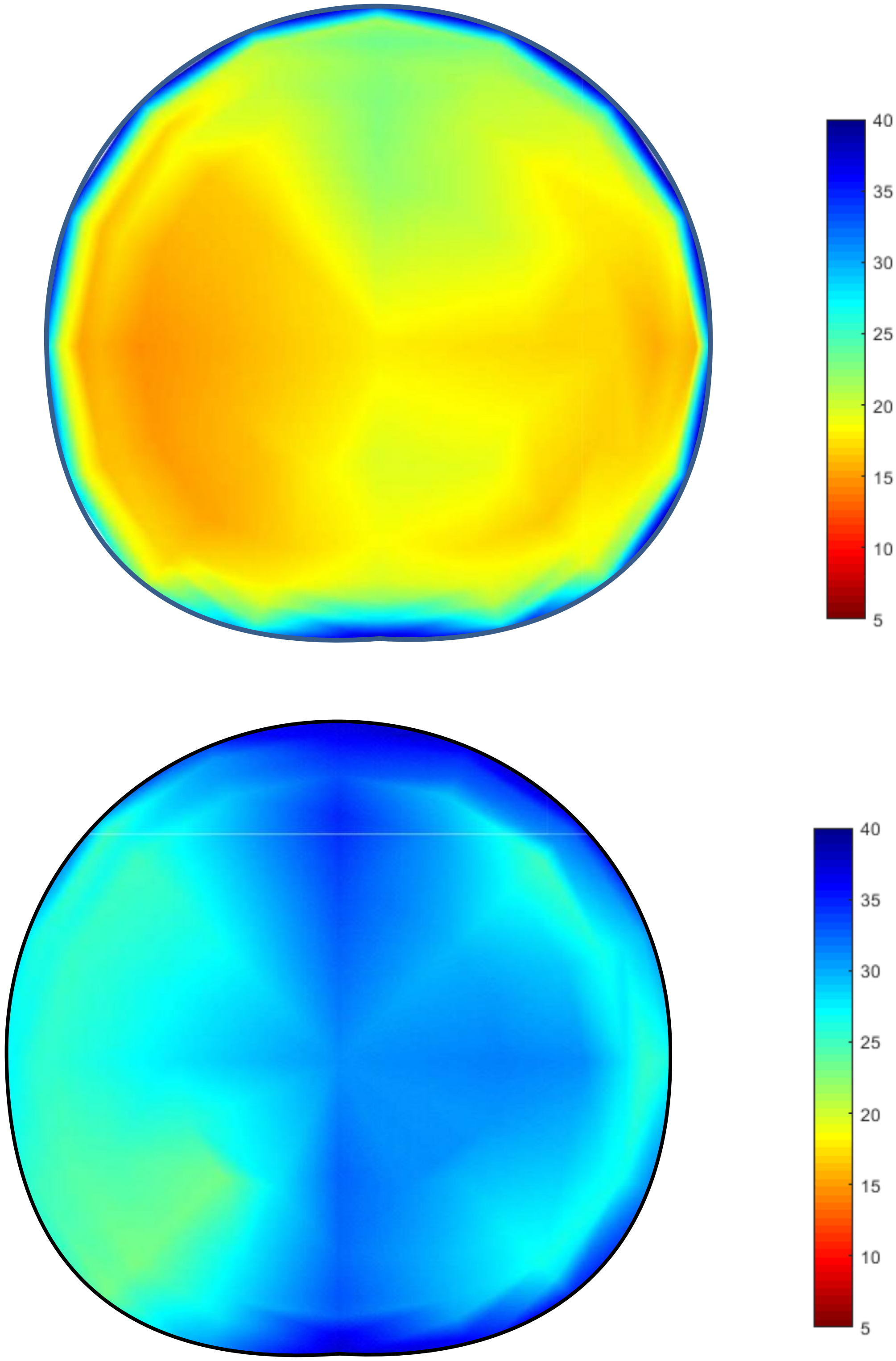


Figure B3. Moisture content (% w.b.) distribution for 1st cutting bales wrapped with 4 layers (top) or 8 layers (bottom) of black plastic stretch film. Maps generated by collecting moisture content estimates using a conductance moisture sensor at locations on the bale north and south faces (see fig. 4.). Scale located to right of figure.

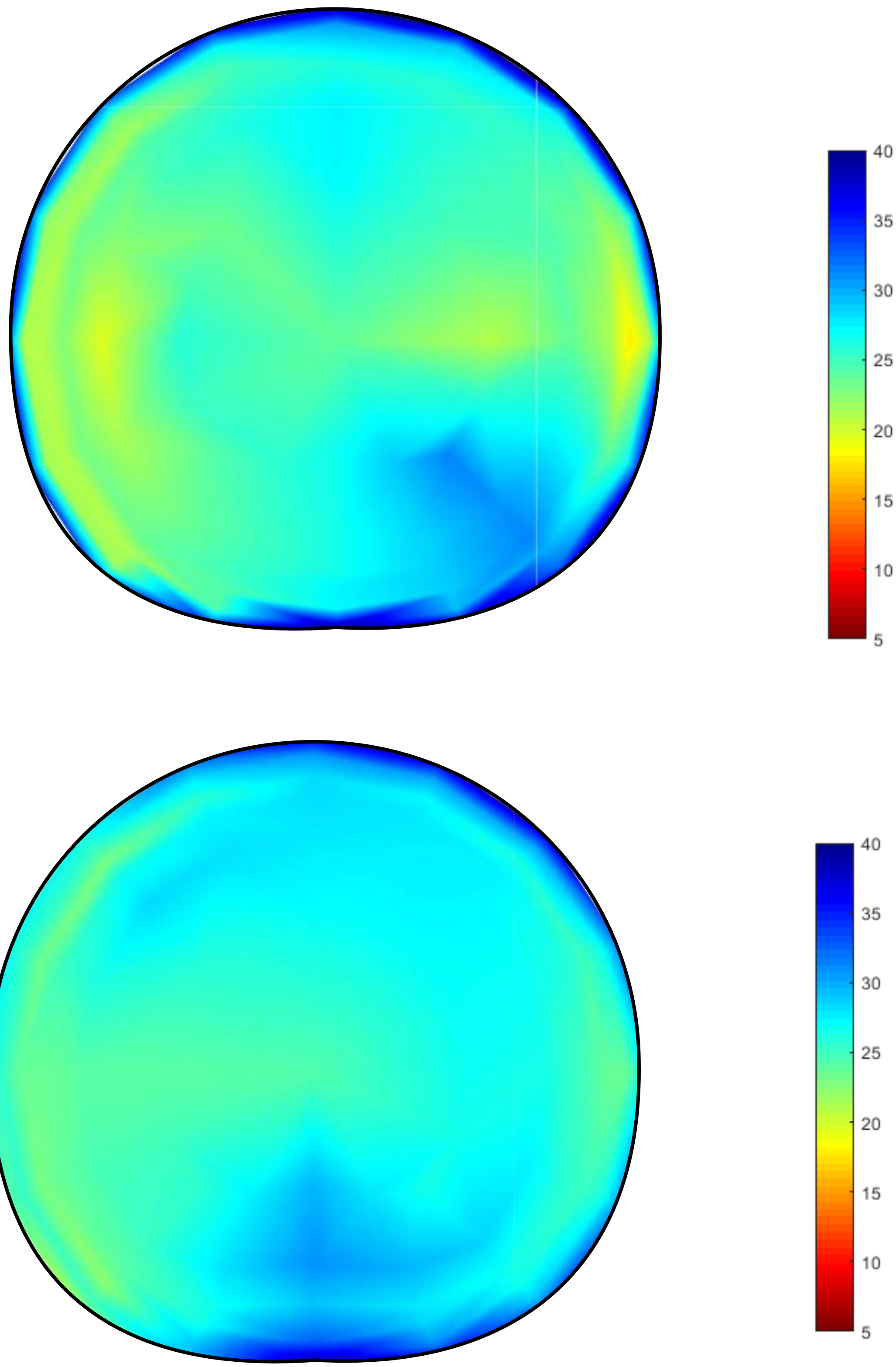


Figure B4. Moisture content (% w.b.) distribution for 1st cutting bales wrapped with 4 layers (top) or 8 layers (bottom) of white plastic stretch film. Maps generated by collecting moisture content estimates using a conductance moisture sensor at locations on the bale north and south faces (see fig. 4.). Scale located to right of figure.

APPENDIX C

Moisture Distribution Images

Second Cutting Alfalfa Bales

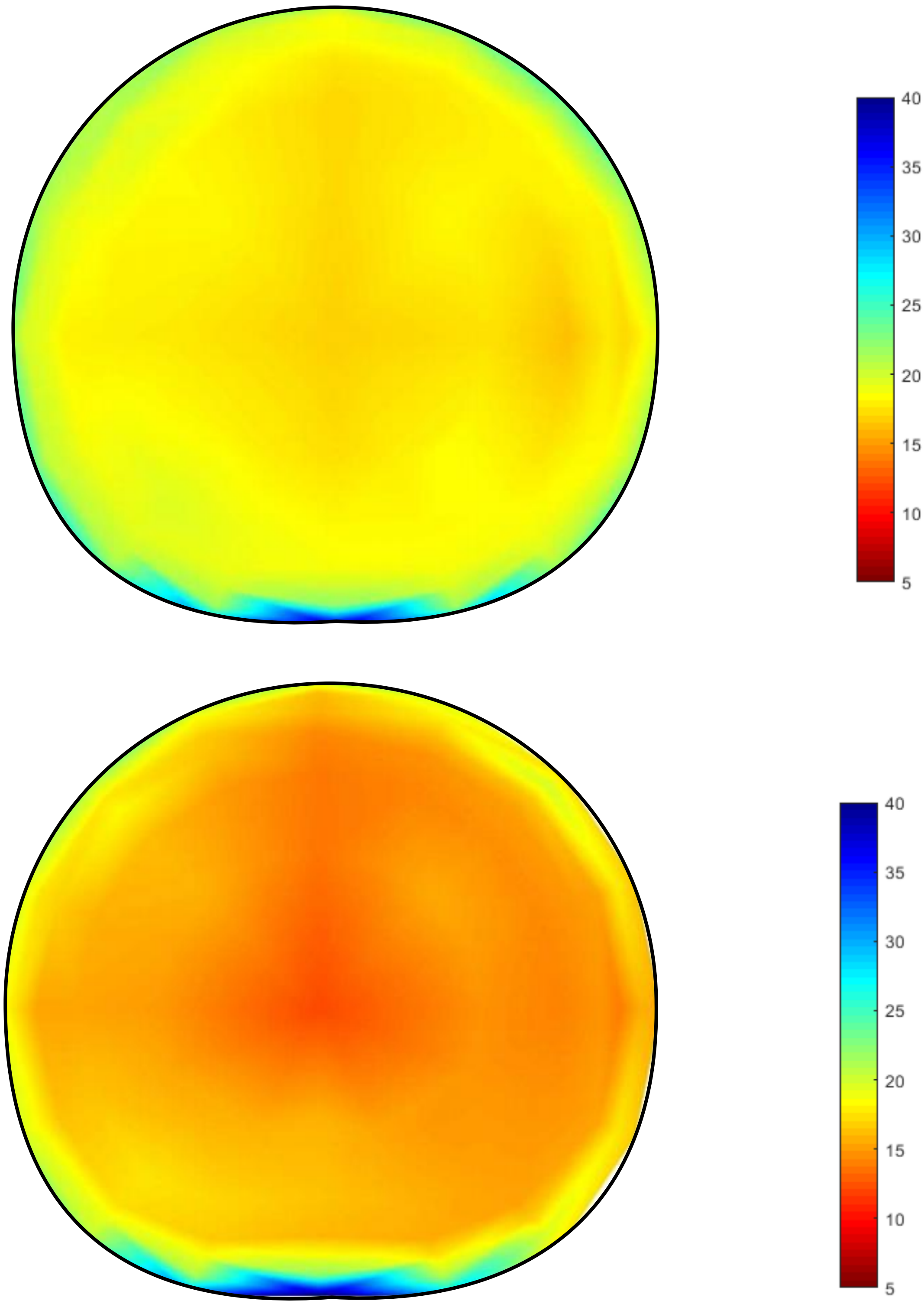


Figure C1. Moisture content (% w.b.) distribution for 2nd cutting bales stored outdoors unwrapped (top) or wrapped in breathable film (bottom). Maps generated by collecting moisture content estimates using a conductance moisture sensor at locations on the bale north and south faces (see fig. 4.). Scale located to right of figure.

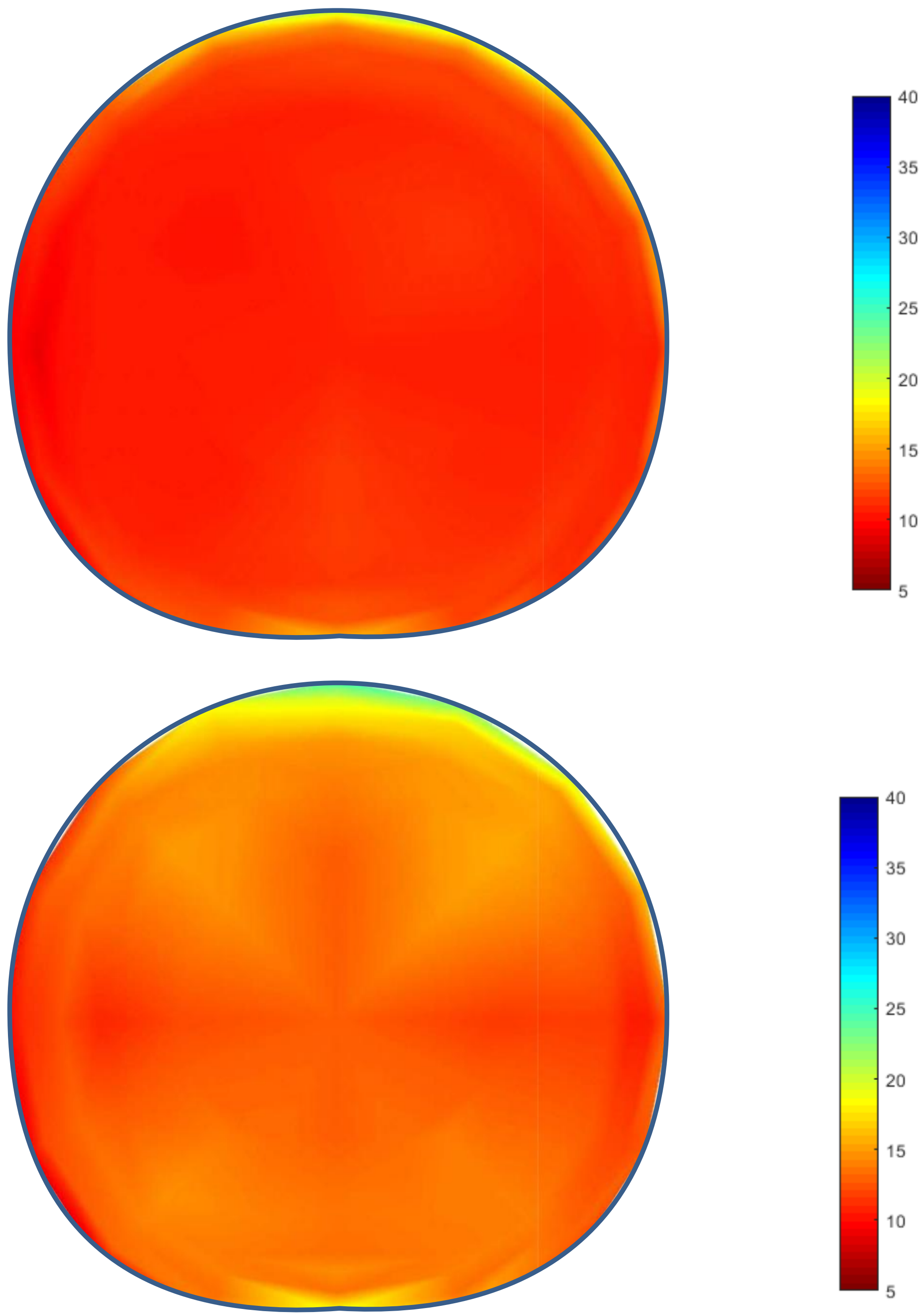
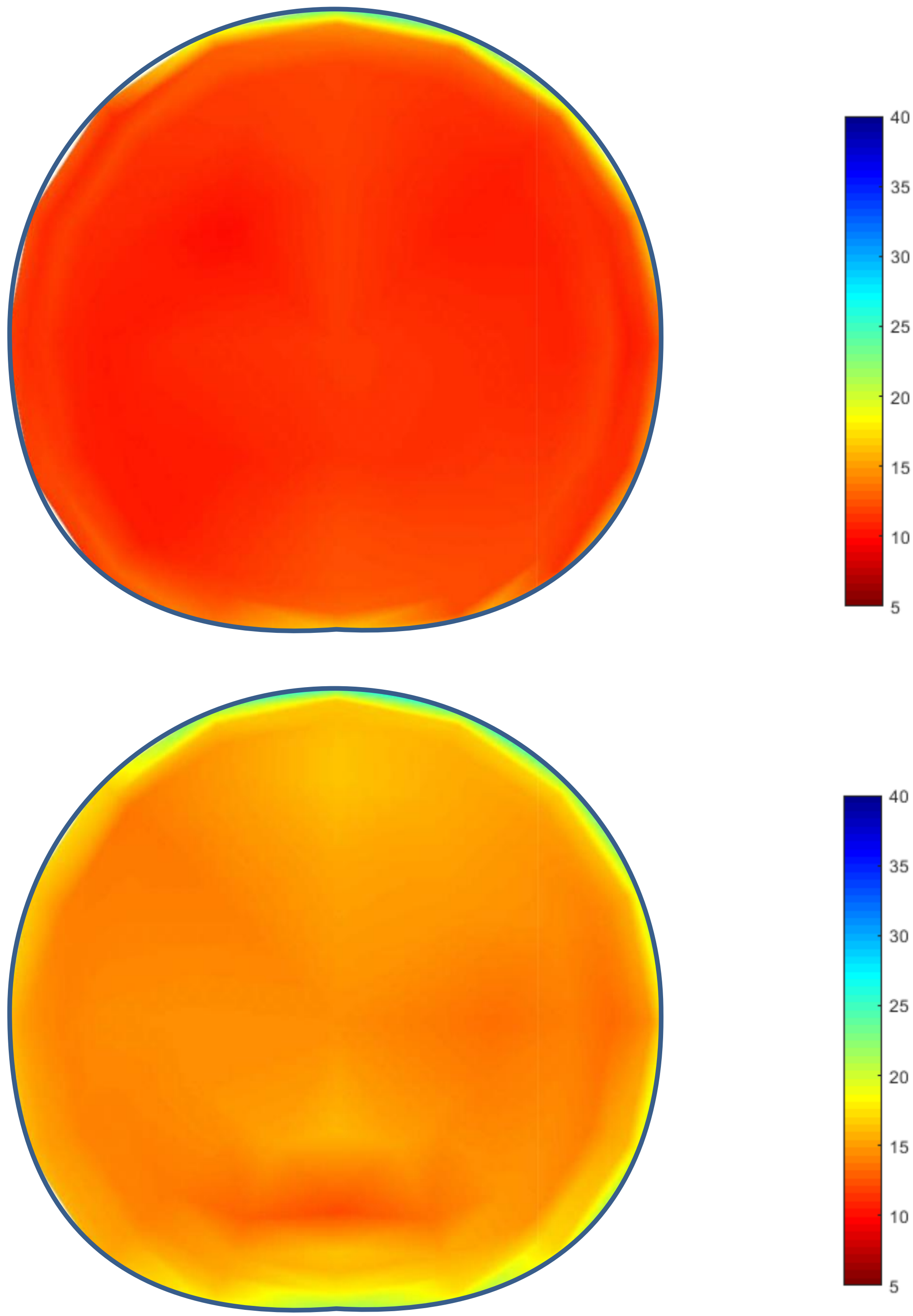


__Figure C2.__ Moisture content (% w.b.) distribution for 1st cutting bales wrapped with 4 layers (top) or 8 layers (bottom) of black plastic stretch film. Maps generated by collecting moisture content estimates using a conductance moisture sensor at locations on the bale north and south faces (see fig. 4.). Scale located to right of figure.



<u>Figure C3.</u> Moisture content (% w.b.) distribution for 2nd cutting bales wrapped with 4 layers (top) or 8 layers (bottom) of white plastic stretch film. Maps generated by collecting moisture content estimates using a conductance moisture sensor at locations on the bale north and south faces (see fig. 4.). Scale located to right of figure.