The Effect of Alfalfa Cultivar and Round Bale Wrap-type and Outdoor Storage Length on Dry Matter, Forage Quality, Beef Cattle Preference, and Hay Waste

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Abstract

Large round bales are commonly fed to livestock; however, it has been well documented that outdoor storage can negatively impact dry matter (DM) and forage quality. These factors, in addition to mold growth, can influence dry matter intake (DMI) and hay waste by livestock animals. To combat this, new wrap-types and alfalfa (*Medicago sativa L.*) cultivars have been introduced but these technologies are not well understood. The objectives of this research were to evaluate time required to wrap large round bales, determine changes in DM and forage quality, and examine the economics of reduce-lignin and reference alfalfa hay wrapped in twine, net wrap and B-Wrap while in outdoor storage. Then to determine preference of beef cattle and hay waste when alfalfa hay had been stored in the different wrap-types. Hay was baled into 24 large round bales; 12 bales each of reduced-lignin and reference alfalfa. Within each cultivar, four replicates were bound with each wrap-type. Using stopwatches, time to bind each bale was recorded. At the time of harvest and every 90 days (±3 days) for 365 days, individual bales were weighed and cored to determine DM loss and changes in forage quality. Twine required the most time to wrap a bale (56 seconds) compared to B-Wrap (28 seconds) and net wrap (18 seconds; $P < 0.01$). Alfalfa cultivar had minimal effects on the parameters measured; therefore, the interaction of wrap type and storage length was reported. After 365 days in outdoor storage, DM losses were 7% for twine wrapped bales, 5% for net wrap bales, while B-Wrap bales maintained DM. Changes in forage quality were commonly observed at ≥180 days of storage with a dilution of nonstructural carbohydrates and a concentration of insoluble fiber components. B-Wrap bales had a higher dollar value compared to net wrap and twines wrapped bales at 180 and 270 days in storage. Then, alfalfa hay (n=24) stored outdoors for 15 months in plastic twine, net wrap, and B-Wrap. After the storage period, round bales were fed in a switchback design to 18 Angus cow-calf pairs. Pairs had *ad libitum* access to three round bales, one of each wrap-type, in individual feeders for 48-hour periods (n=8). Feeders were weighed and waste surrounding feeders was collected at 24 and 48 h to calculate DMI and hay waste. Total DMI, and DMI during the first 24 hours, were greater in B-Wrap bales compared to twine wrapped bales indicating the cattle preferred hay wrapped in B-Wrap. Net wrapped bales resulted in similar forage quality and DMI to both B-Wrap and twine wrapped bales. However, no difference in hay waste were observed between the wrap-types. These results indicate that B-Wrap appears to shed precipitation better resulting in a conservation of DM and forage quality compared to twine and net wrap while also being preferentially consumed over twine wrap.

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CHAPTER 1:

REVIEW OF LITERATURE

Introduction

Alfalfa (*Medicago sativa* L.) is the most widely cultivated perennial forage crop in the world and ranks among the top five most valuable crops in the United States (NASS, 2019). Alfalfa production in the United States was estimated at 52.6 million tons on 16.6 million acres in 2018. However, alfalfa hay production has decreased by 6% and on 2% less acres than in 2018 (NASS, 2019). Reflecting the decrease in production, the price of alfalfa hay increased throughout 2018 (NASS, 2019).

Alfalfa is primarily utilized as feed for a wide variety of livestock including dairy and beef cattle, horses, sheep, and aquaculture due to high nutrient content (Hanson et al., 1988). Due to the decreased production and increased prices, producers and livestock owners are seeking ways to get the most from their alfalfa crop by reducing dry matter (DM) loss and detrimental changes in forage quality during storage. Additionally, owners are keen on reducing hay waste when feeding livestock.

Alfalfa in Cattle Rations

Alfalfa is generally utilized as a protein or energy supplement in beef cow rations during winter months or periods of drought when access to pasture is limited. Beef cow rations during these times commonly consist of lower-quality harvested forage or poor pasture. Additionally, alfalfa can be supplemented to increase protein and/or energy intake when demands increase during late gestation and lactation (NRC, 2000). The addition of alfalfa supplementation can also increase DM intake of lower-quality forages, decreasing the reliability on other energy supplements (DelCurto et al., 1990; Weder et al., 1999). While alfalfa is a useful forage when feeding livestock, the lignin content of alfalfa can limit the utilization and digestibility by livestock (Sewalt et al. 1997; Casler et al., 2002).

Lignin and Digestibility

Lignin is a structural carbohydrate that is the second most abundant component of plant cell walls as it provides rigidity and strengthens the plant stem helping to maintain an upright position (Inoue et al. 1998; Guo et al., 2001). Lignin deposition is vital for plant growth and maturity; therefore, as a plant matures, the lignin concentration increases, filling the space between cellulose, hemicellulose and pectins, and linkages with hemicellulose (Albrecht et al., 1987; Sewalt et al., 1997; Inoue et al., 1998; Casler and Vogel, 1999. While plant lignification is critical for normal growth, the lignin concentration of a plant decreases the feeding value by negatively affecting microbial degradation and digestion by intestinal enzymes (Buxton & Hornstein, 1986; Liu & Peiqiang, 2011). The lignin concentration has been reported to be the limiting factor in both *in vitro* digestibility of plant cell-wall polysaccharides (Albrecht et al., 1987; Jung et al., 2012; Morrison, 1979) and *in vitro* DM digestibility (DMD) of whole plant forage (Casler, 1986, 1987; Reddy et al., 2005). The negative effects on digestibility have been attributed to strong negative correlations between the lignin concentration and forage digestibility (Albrecht et al., 1987; Casler, 1987; Jung et al., 1997a; b; Reddy et al., 2005). Because lignin concentration has an influence over forage digestibility, the quality and digestibility may be improved if plants were selected or modified to reduce the lignin concentrations (Buxton & Hornstein, 1986; Sanderson et al., 1989; Jung & Lamb, 2006; Lamb et al., 2014). Casler (1987) and Understander et al. (2009) suggested that even small decreases in lignin concentration of forages could improve forage digestibility. These improvements in forage digestibility could result in significant gains in animal performance. A positive relationship was reported between greater *in vitro* DMD and average daily gains. A 1% increase in *in vitro* DMD lead to a 3.2% increase in beef cattle average daily gains (Casler & Vogel, 1999).

Reduced-Lignin Alfalfa

To improve forage digestibility and feed quality of alfalfa, several experimental lines of alfalfa have been developed with a down-regulation of the caffeic acid 3-O-methltransferase (COMT) and caffeoyl CoA 3-O-methlytransferase (COMMT) lignin biosynthetic genes (Guo et al., 2001; Inoue et al., 1998; Marita et al., 2003; Getachew et al., 2011). When comparing lignin concentration of the reduced-lignin alfalfas, the experimental cultivars showed a 4 to 29% decrease in stem lignin concentration and a 1 to 24% decrease in whole plant lignin concentration when compared to reference cultivars (Guo et al., 2001a;b; Marita et al., 2003; Reddy et al., 2005; Undersander et al., 2009; Getachew et al., 2011). The wide range in lignin reduction was attributed to several factors including the specific gene that was down-regulated (Guo et al., 2001a; b; Marita et al., 2003; Undersander et al., 2009; Getachew et al., 2011), or the method to determine lignin concentration (Guo et al., 2001a; b; Jung et al., 2012). The experimental cultivars of reduced-lignin alfalfa have also shown promise to increase forage digestibility. These cultivars have shown an increase *in vitro* DMD, *in vitro* neutral detergent fiber digestibility (NDFD), and *in situ* rumen digestibility (Guo et al., 2001b; Mertens & McCaslin, 2008; Reddy et al., 2005; Undersander et al., 2009; Weakley et al., 2008; Getachew et al., 2011). The reduced-lignin alfalfa cultivars have also shown a decrease in neutral detergent fiber (NDF) and an increase in non-fiber carbohydrates compared to reference cultivars (Guo et al., 2001b; Reddy et al., 2005 Getachew et al., 2011; Li et al., 2015). Interestingly, crude protein (CP) concentrations were similar in the reduced-lignin alfalfa cultivars compared to the reference cultivars (Getachew et al., 2011; Li et al., 2015). Although the experimental reduced-lignin alfalfa cultivars showed promise, it remained unclear how these cultivars would perform in field conditions. Grev et al. (2017) evaluated the commercially available reduced-lignin alfalfa cultivar '54HVX41' under diverse field conditions and found a reduction in acid detergent lignin (ADL), increase in NDFD48, but similar CP and NDF. Getachew et al. (2018) found similar results when evaluating different reduced-lignin alfalfa cultivars. While the results of these studies showed increased forage digestibility *in vitro*, *in vivo* digestibility remains mostly unknown.

Few researchers have evaluated the digestibility of reduce-lignin alfalfa in comparison to reference cultivars. Mertens and McCaslin (2008) evaluated the digestibility of reduced-lignin and reference alfalfa hay when fed to lambs and found that DMD and NDFD48 were greater for the reduced-lignin alfalfa hay. When several reduced-lignin alfalfa hays were included at 50% of lactating dairy cow rations, NDFD48 was greater in the reduced-lignin alfalfa cultivars. The increase in fiber digestibility translated into 1.3 kg more milk produced per head per day when compared to reference alfalfa cultivars (Weakley et al., 2008).

In contrast, Peterson et al. (2018) assessed the performance of beef cattle when consuming reduced-lignin alfalfa hay compared to a reference cultivar. There were no differences between the alfalfa cultivars which explains why no differences were observed in beef cattle performance, which included body weight, average daily gain, DM intake, or grain to feed ratio. Additionally, researchers did not observe any differences in *in situ* DM disappearance. The lack of differences in forage nutritive value could be attributed to the maturity in which the alfalfa was harvested; alfalfa was harvested at a later maturity potentially masking some quality differences. Peterson et al. (2018) also raised concern whether the reduced-lignin cultivars expressed reductions in lignin during the establishment year, indicating further research should be conducted.

When evaluating the digestibility of reduced-lignin alfalfa hay in mature horses, Grev et al. (2018) found a 4% increase in the DMD of reduced-lignin alfalfa hay compared to the reference alfalfa but found no difference in NDFD48. Though these results were unique when compared to other species, the authors did note large variability in fiber digestion by individual horses used in the study.

While research continues to discern the digestibility of reduce-lignin alfalfa cultivars, it is also necessary to evaluate how reduced-lignin alfalfa hay will perform in outdoor storage. To date, there is no research evaluating how reduced-lignin alfalfa hay will performs when stored uncovered, outdoors in long-term, storage. Future research should address if reduced-lignin hay is more susceptible to the effects of weathering compared to reference alfalfa.

Storage Dry Matter and Quality Losses

Methods of hay storage have been shown to have a significant effect on the loss of DM and forage nutritive value. Most of the research has focused on the storage of large round bales as they tend to be commonly stored outside due to their size and shape. Dry matter losses and subsequent changes in forage nutritive value are driven by exposure to the elements, especially precipitation. The moisture accumulates in the weathered layer leaching the soluble nutrients such as water-soluble carbohydrates, soluble nitrogen, soluble minerals (e.g. potassium) and lipids (Fonnesbeck et al., 1986) from the forage while providing an environment for microbial growth. Microbial activity also accounts for the loss of soluble nutrients as microbes utilize these nutrients (Rees, 1982; McGechan, 1989). The loss of soluble nutrients results in DM loss (Hloedversson et al., 1984; Rotz & Abrams, 1988). The loss of these soluble nutrients also leads to changes in forage nutritive value. As the soluble nutrients are lost, the insoluble fiber components, NDF and ADF, become more concentrated (Harrigan & Rotz, 1994).

Outdoor Storage Methods

Dry matter loss and changes in forage quality have been well described for many different storage methods. Anderson et al. (1981) evaluated the storage of 1st and 2nd cutting alfalfa round bales stored indoors and outdoors over winter; however, a specific time frame was not stated. On average, they observed DM losses of 3% when bales were stored indoors, and DM losses of 14% when bales were stored outdoors. Additionally, when examining the changes in forage nutritive value, they found no change in CP, an increase of 6% ADF, and an 8% decrease in *in vitro* DM disappearance when bales were stored outdoors compared to indoors (Anderson et al., 1981).

Verma and Nelson (1983) stored alfalfa and ryegrass (*Lolium L.*) round bales outdoors on several different surfaces including gravel, sod, elevated racks with and without plastic covers, old automobile tires, and indoors while alfalfa round bales were outdoors on elevated racks with and without cover. Ryegrass bales were stored outdoors for 12 months while the alfalfa bales were stored for 16 months. Dry matter losses for the ryegrass bales ranged from 2 to 35% with bales stored indoors having the least DM loss and bales stored on the tires showing the greatest DM losses. Dry matter losses in the alfalfa bales were 49% for bales stored on racks and 45% for bales stored on racks with cover. Authors noted that alfalfa bales stored on the rack with cover were uncovered for the last four months, possibly attributing to the greater losses observed. Generally, ryegrass bales had similar NDF and CP, but bales stored inside and on racks with cover observed little change *in vitro* digestible DM, while other storage methods resulted in a decrease of 4 to 8% of digestible DM (Verma & Nelson, 1983).

Similarly, Brasche and Russell (1988) stored alfalfa-bromegrass (*Bromus madritensis L.*) and bromegrass round bales outside uncovered on the ground (control), raised on tires, and covered with plastic sheets (protected) for 20 to 26 weeks. They found that protected grass alfalfa mix and bromegrass bales had higher DM retention lower concentrations of NDF and ADF, and greater *in vitro* digestible DM. However, similarly to previous reports, CP did not change due to storage method (Brasche & Russell, 1988).

Belyea et al. (1985) stored alfalfa round bales in a barn, outdoors uncovered in single rows, and covered in stacks two or three high, but did not quantify the exact storage period. Bales stored indoors had the least DM loss at 2.5% while bales stored outdoors uncovered had the greatest loss at 15%. The bales stored outdoors and covered averaged 6% DM loss. The teams reported the depth of the weathered layer was 19 cm, which accounted for 32 to 46% of the dry bale weight (Belyea et al., 1985).

Collins et al. (1987) stored alfalfa round bales outdoors on the ground, on 20 cm diameter poles, covered with plastic, or indoors. Additionally, they stored large square bales indoors. Round bales stored indoors lost 4.6% DM which was similar to the square bales stored indoors (5.1%). However, DM losses were greater in bales stored outdoors on the ground (10.9%), compared to bales stored outdoors covered (5.2%) and those elevated off the ground (7.5%). Similar to Belyea et al. (1985), they noted the proportion of weathered material. The weathered layer in bales stored outdoors on the ground constituted 15.5% of the initial bale, whereas this layer was 11.6% in bales stored elevated off the ground. No weathered layer was observed in the bales stored indoors. Generally, the total NSC decreased in all bales except those stored indoors, which indicates the leaching of the soluble nutrients of outdoor stored hay. Fiber components, ADF and NDF, were concentrated in all storage methods; however, a greater concentration was observed in the weathered layer of bales stored outdoors without cover compared to those stored under cover and indoors (Collins et al., 1987).

Huhnke (1987) stored alfalfa round bales outdoors uncovered and covered on the ground or on wooden pallets as well as indoors for 8 months. Dry matter losses for bales uncovered outdoors on the ground and on pallets were 13.1% and 8.6%, respectively, but were not different from each other. Dry matter loss in bales stored outdoors covered on the ground (6.5%), covered on pallets (1.9%), or stored indoors (1.9%) were similar between, and less than uncovered bales stored outdoors on the ground or on pallets. This shows the importance of providing protection from both above and below bale precipitation and moisture. Similar to previous reports, CP did not change due to storage method, but NDF and ADF were greater in bales stored outdoors without cover compared to those with cover. Additionally, bales stored with covers or indoors had greater *in vitro* DM disappearance compared to bales stored without cover. The author confirmed that protection from precipitation (e.g. covering the bales) and ground moisture (e.g. elevating off the ground) were key factors when storing bales outdoors (Huhnke, 1988).

Round-Bale Covering

As the forage industry learned more about the significant losses of DM and forage nutritive values, new products were introduced to the market in an attempt to reduce losses. In the mid-1980's a product generally known as net wrap became available that was advertised to better shed precipitation compared to sisal or plastic twine wrap. Net wrap is made from a woven polyethylene mesh, and quickly became the industry standard due to increased baling efficiency and reduced DM loss and negative changes in forage nutritive values compared to the twine wrapped bales.

Russell et al. (1990) evaluated the storage of alfalfa-bromegrass hay in both the net wrap and sisal twine tied bales stored outdoors uncovered for 9 months. They examined both the outer 30 cm layer and the core of all bales. They found in the outer 30 cm, net wrap bales had 5.1% greater *in vitro* digestible DM while having lower concentrations of NDF, ADF and ADL compared to twine tied bales. The net wrap bales had 4.7% greater retention of total DM and un-weathered DM compared to twine tied bales; however, the experimental design did not allow for comparison between net wrap bales and bales stored indoors (Russell et al., 1990).

Bledsoe and Bates (1992) evaluated alfalfa-orchardgrass (*Dactylis glomerate L.*) hay when stored outdoors and indoors for 8 months and wrapped in twine, two different net wraps (woven mesh and rectangular grid mesh), and a cling wrap (plastic covering). They found that none of the bale coverings used were effective at fully protecting against weathering and observed loses in digestible DM and forage quality parameters. Authors noted there was a tendency for the net and cling wraps to better preserve digestible DM and forage quality compared to twine tied bales. Additionally, the authors observed the woven mesh net wrap, which is currently on the market, was superior over the rectangular grid mesh. When hay stored in the different wraps was subject to a human sensory panel, the two net wraps tended to be more preferred; however, no wrap-type performed better than bales stored indoors. Heavy rainfall throughout the storage period was recorded (≥7 cm each month), which may have masked some differences (Bledsoe & Bales, 1992).

Harrigan and Rotz (1994) evaluated the storage of alfalfa round bales in twine stored indoors and twine, full plastic covering, and net wrap stored uncovered outdoors on pallets for 6 to 9 months. To determine changes in the outer layer, the outer 10 cm was sampled separately from the remaining portion of the bale. Dry matter loss in net wrap bales (16.3%) were similar to twine tied bales (16.5%) indicating there were little differences in the wrap-types ability to shed precipitation for 6 to 9 months. However, the DM loss in bales stored in plastic wrap (9.6%) tended to be similar to those stored inside (6%). There were no changes in forage nutritive value in the interior of the bales in any wrap type, but NDF was more concentrated in twine tied bales compared to net wrap bales. Unlike previous reports, a decrease in CP was observed when bales were stored outdoors. The authors theorized this was due to microbial respiration which exhausted soluble carbohydrates, therefore, some protein was utilized. However, the authors did not measure the loss of soluble carbohydrates (Harrigan & Rotz, 1994).

Taylor et al. (1995) evaluated the storage of alfalfa round bales stored indoors and outdoors in plastic twine and net wrap for 9 months. No differences in DM losses were observed between the wrap-types or bales stored indoors or outdoors with DM losses ranging from 0.1 to 5.3%. Twine tied bales had greater concentration of NDF (7.1% increase) compared to net wrap bales (4.6% increase); however, these changes were not expected due to the minimal DM losses observed. When examining the outer layer (10 cm), NDF was more concentrated in twine tied bales compared to net wrap bales. Below average rainfall during the storage period may explain the low DM losses and lack of difference between wrap-types. These results do suggest that if storing hay in arid regions, net wrap may not be necessary (Taylor et al., 1995).

More recently, Shinners et al. (2009) wrapped alfalfa round bales in sisal and plastic twine, to-edge and cover-edge net wrap, plastic wrap, and indoor storage for 5 or 11 months. To-edge net wrap covered the rounded surface of the bale, while the cover-edge net wrap wrapped over the flat sides of each bale.

Both net wraps performed similarly, were averaged, and presented as net wrap. Net wrap bales consistently had lower moisture content in the outer layer and lower DM losses compared to twine tied bales. Dry matter losses averaged 19.5%, 11.3% and 7.3% for sisal twine, plastic twine, and net wrap bales, respectively; however, losses were lowest when bales were wrapped in plastic wrap (3.1%) or stored indoors (1.8%). While losses were less in bales wrapped in plastic, the authors observed condensation on the interior of the plastic wrap resulting in green patches of algae and black mold. No differences in forage nutritive values were observed in the wrap-types; however, net wrap bales tended to have better nutrient retention in the outer layer compared to twine wrapped bales. The interior of the bales remained unchanged in all wrap-types (Shinners et al., 2009).

The newest development in bale wrapping is breathable films that shed precipitation. Shinners et al. (2010) evaluated the storage of perennial grass round bales wrapped in sisal and plastic twine, net wrap, breathable film, and plastic wrap for 293 to 334 days. Dry matter losses averaged 3.8%, 4.8%, 7.5%, 8.7%, and 14.9% for plastic film, breathable film, net wrap, plastic twine, and sisal twine, respectively. Similar to their previous work, Shinners et al. (2010) noted that plastic wrapped bales had green algae and black mold growth due to condensation on the bale covering. The DM loss of the breathable film was similar to plastic wrapped bales; however, there were no reports of green algae growth indicating that the breathable film did not trap moisture inside the bale (Shinners et al., 2010).

More recently, Shinners et al. (2013) evaluated alfalfa hay wrapped in several breathable film products and compared them to net wrap after 10 months in outdoor storage. The breathable films conserved DM while losses were similar to net wrap bales stored doors. The concentration of NDF was less in the breathable films and digestible DM was greater. The breathable film wraps included an early test version of a newly marketed product, B-Wrap®. Future research should investigate the impact of DM losses and changes in forage nutritive values when round bales are wrapped in B-Wrap® and storage outdoors (Shinners et al., 2013).

Livestock Feeding Losses

While hay losses during storage can be substantial, hay waste associated with feeding can also cause significant losses. Feed costs account for 63% of cow management and are the greatest variables in Midwest producer' profitability (Miller et al., 2016). Therefore, reducing hay waste is economically importance for cattle producers. Some theorize that hay waste is most likely due to decreased feed palatability. However, palatability is complex because there are many aspects that influence palatability in both the feed and the animal. Palatability has been defined as "dietary characteristics or conditions which stimulate a selective response by the animal" (Greenhalgh & Reid, 1974; Church, 1979). Therefore, palatability can be altered by physical (e.g., DM content and particle size), and chemical (e.g., smell and taste) factors, but also the metabolic state of the animal (Matthews, 1983; Gallouin & Le Magnen, 1987). A common measure of palatability is an animal's preference, or intake of a particular feed (Baumont, 1996). Measuring forage intake is commonly used to determine cattle preference for both fresh pasture and harvested forages. Similar methods have been utilized to determine how storage conditions influence palatability by measuring dry matter intake and subsequent hay waste.

Although several researchers have evaluated the impact of storage on round bale DM losses and quality, fewer have focused on the impact of feeding stored bales to livestock. Nelson et al. (1983) observed feeding losses of 13 to 20% when large round bales were stored outdoors without cover, but only 1% for bales stored outdoors with cover or indoors. Similarly, Belyea et al. (1985) evaluated the feeding losses of alfalfa round bales stored indoors and with and without cover outdoors. Growing dairy heifers consumed less hay (2.11 kg/100kg BW) from round bales stored outdoors without cover compared to those stored indoors or outdoors with cover (2.35 and 2.25 kg/100kg BW, respectively). Heifers wasted 12 to 15% of the hay stored indoors or outdoors covered and wasted 25% of the hay fed that was stored outdoors without cover. Researchers found greater average daily gains when heifers consumed hay stored indoors or outdoors under cover compared to bales stored outdoors without cover. Storing hay indoors or covered outdoors reduced feeding losses by as much as 50% and increased average daily gain when fed to growing dairy heifers (Belyea et al., 1985).

Additionally, Baxter et al. (1986) evaluated the feeding losses of alfalfa-orchardgrass hay that was packaged in large square and round bales and stored indoors, and large round bales stored outdoors on the ground or on tires. Bales were stored for 5 to 7 months then fed to lactating dairy cows. They measured intake as a percent of the whole bale fed and found that cows utilized 93% of bales stored indoors compared to 74 and 67% of bales stored outdoors on tires or the ground, respectively. Cows wasted 17% of bales stored outdoors on the ground, 14% when stored outdoors on tires, and only 4% when stored indoors. Cows also produced less milk when consuming bales that were stored outdoors compared to indoors (Baxter et al., 1986).

Russell et al. (1990) investigated the effect of storing alfalfa-bromegrass round bales in net wrap and twine for 5 months on DM intake and hay waste in sheep. When lambs were fed 90% of what their forage *ad libitum* diet was during acclimation, DM intake was greater from net wrap (2.3% bodyweight; BW) bales compared to twine (1.8% BW) wrapped bales. Intake was 20% greater when fed from net wrap bales; however, no measurements of animal performance were collected. DM intake is known to be a primary factor influencing animal performance (Waldo & Jorgensen, 1981). Therefore, the 20% decrease in intake when feeding from the twine tied bales may have a negative impact on animal performance. Researchers noted that twine tied bales had a musty odor commonly associated with mold growth which may have influenced palatability. Unfortunately, mold growth was not quantified. In addition, lambs refused more hay from bales tied in twine (5%) compared to net wrap bales (2%). The results of this study suggest that bale wrap-type during storage can affect DMI and possibly animal performance (Russell et al., 1990).

Finally, Shinner et al. (2013) evaluated the impact of harvesting alfalfa round bales in net wrap and several breathable films both indoors and outdoors for 10 months. All round bales were processed and fed in bunkers to beef heifers. Heifers preferred to consume bales wrapped in breathable film and bales stored indoors over the net wrap bales stored outdoors. Heifers consumed 57, 35, and 52% of the hay DM from the breathable film, net wrap stored outdoors, and net wrap stored indoors, respectively (Shinners et al., 2013). This study agrees with Russell et al. (1990), indicating that bale wrap-type during storage may influence animal preference of hay.

Combined, these studies suggest that livestock prefer hay that was stored indoors or while covered outdoors and highlight the importance of storage method on hay waste and feeding losses. The impact of newer bale wrap-types on livestock intake and preference has not been thoroughly investigated; therefore, future research should explore this relationship.

Mold and Cattle Preference

Several of the studies previously discussed reported suspected mold growth in round bales stored outside; however, none of the studies tested for the presence of mold or mold quantity. However, previous research has explored the effect of induced mold growth on cattle intake and performance. Mohanty et al. (1969) harvested good quality alfalfa hay and exposed bales to simulated rainfall (7.6 cm) followed by outdoor storage. Mold presence was determined by maximum temperature spikes in the bales and increases in pH; however, mold counts were not determined. Researchers noted deleterious changes in forage quality including brownish coloration of the hay which indicated heat damage. When moldy hay was fed to steers, it resulted in a lower DMI, decreased rumen function, and a decrease in performance. Dry matter intake was 7 kg/day when fed good quality hay compared to 6.5 kg/day when fed the moldy forage. The decrease in DMI combined with a decrease in the production of volatile fatty acids caused a 16% decrease in average daily gain (Mohanty et al., 1969).

Undi et al. (1996) investigated the influence of 3 levels of moldy hay; high (>1.4 x 10^5 CFU/g), moderate (8.5 x 10^4 CFU/g), and low (< 2.0 x 10^4 CFU/g) when fed to dairy calves. Equal amounts of hay from each treatment were feed concurrently and in alternating placement, thereby offering a choice to the calves. Calves preferred hay with low amounts of mold (9.4 kg/6 days) compared to the high and moderate moldy hays (6.8 and 3.6 kg/6 days). Researchers noted that hay with low mold had a green color compared to the moderate and high mold hays which were brown to dark brown in color indicating heating during storage. Unfortunately, animal performance was not measured (Undi & Wittenberg, 1996).

These results indicate that mold formation in hay can influence DMI and may have potentially harmful adverse effects on livestock performance. Long-term studies investigating the effect of moldy forge on livestock performance and health is needed.

Problems With Feeding Moldy Hay

Moldy hay increases the risk for health problems for both humans and animals (Gregory & Lacey, 1963; Nash, 1985; Knudtson & Kirkbride, 1992; Gallo et al., 2015). Mold spores can cause skin and respiratory related reactions in humans (Gregory & Lacey, 1963). In addition to the problems associated with inhalation or skin contact with mold spores, fungi present on the conserved forage can produce secondary metabolites, mycotoxins, which are toxic to humans and animals (DiCostanzo et al., 1996; Whitlow and Hagler, 2005; Zain, 2011; Gallo et al., 2015). However, the presence of mold does not guarantee the production of mycotoxins as not all molds produce toxic metabolites or the metabolites are not essential to the mold's existence (DiCostanzo et al., 1996; Whitlow and Hagler, 2005; Zain, 2011; Gallo et al., 2015). The production of mycotoxins are typically associated with poor field harvest, storage or feeding conditions and are generally associated with the presence of excess moisture (DiCostanzo et al., 1996; Whitlow and Hagler, 2005; Zain, 2011; Gallo et al., 2015). Most common molds producing toxigenic mycotoxins in livestock feeds are *Aspergillus* sp., *Penicillium* sp., and *Fusarium* sp. In ruminants, exposure to mycotoxins can cause decreased animal performance due to disruptions in rumen functionality, increased susceptibility to infections due to immunosuppressive properties, increased risk of mycotic abortions, and decreased fertility (Knudtson & Kirkbride, 1992; DiCostanzo et al., 1996; Whitlow & Hagler, 2005; Gallo et al., 2015).

Previous research has indicated that mold values of 5×10^5 CFU/g or less are considered safe to feed livestock, 5×10^5 to 1×10^6 CFU/g are relatively safe, greater than 1 x 10^6 CFU/g should be fed with caution, and greater than 5 x 10^6 CFU/g should not be fed to livestock (Adams et al., 1993). Given the potential health complications associated with feeding moldy hay, and the lack of information focused on mold formation in outdoor stored hay, future research should examine the interaction between bale wrap-type, mold formation, and livestock performance and health when fed outdoor stored hay.

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CHAPTER 2

Effect of alfalfa cultivar and bale wrap-type on dry matter and forage quality of large round bales in outdoor storage

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CHAPTER SUMMARY

Large round bales are commonly fed to livestock; however, it has been well documented that outdoor storage can negatively impact dry matter (DM) and forage quality. To combat this, new wrap-types and alfalfa cultivars have been introduced; however, these technologies are not well understood. The objectives of this research were to evaluate time required to wrap large round bales, determine changes in DM and forage quality, and examine the economics of reduce-lignin and reference alfalfa hay wrapped in twine, net wrap and B-Wrap® while in outdoor storage. Hay was baled into 24 large round bales; 12 bales each of reduced-lignin and reference alfalfa. Within each cultivar, four replicates were bound with each wrap-type. Using stopwatches, time to bind each bale was recorded. At the time of harvest and every 90 days (±3 days) for 365 days, individual bales were weighed and cored to determine DM loss and changes in forage quality. Data were analyzed using the MIXED procedure of SAS, statistical significance was set at $P \leq 0.05$. Twine required the most time to wrap a bale (56 seconds) compared to B-Wrap® (28 seconds) and net wrap (18 seconds; P <

0.01). Alfalfa cultivar had minimal effects on the parameters measured; therefore, the interaction of wrap type and storage length was reported. After 365 days in outdoor storage, DM losses were 7% for twine wrapped bales, 5% for net wrap bales, while B-Wrap® bales maintained DM. Changes in forage quality were commonly observed at ≥180 days of storage with a dilution of nonstructural carbohydrates and a concentration of insoluble fiber components. B-Wrap® bales had a higher dollar value compared to net wrap and twines wrapped bales at 180 and 270 days in storage. B-Wrap® appears to better shed precipitation resulting in a conservation of DM and forage quality compared to twine and net wrap.

INTRODUCTION

Large round bales are commonly fed to livestock, especially cattle and horses and can be stored in various ways, including indoors and outdoors with or without cover. Outdoor storage can be advantageous for producers with limited indoor storage; however, it has been well documented that storing hay outdoors negatively impacts dry matter (DM) loss and forage quality. Dry matter losses when large round bales were stored outside without cover ranged from 7 to 49%, compared to only 2 to 6% when stored indoors (Verma and Nelson, 1983; Huhnke, 1988; Harrigan and Rotz, 1994; Shinners et al., 2009). The wide range of DM loss was influenced by many factors including the length of storage, regional climate, and bale wrap-type (Verma and Nelson, 1983; Bledsoe and Bales, 1992; Taylor et al., 1994).

In addition to DM loss, changes in forage quality were observed when large round bales were stored outdoors, especially in the outer layer of the bale. These changes can be attributed to the introduction of environmental moisture driving microbial activity and leaching soluble nutrients; therefore, concentrating the fiber components (Harrigan and Rotz, 1994). Previous research found a concentration of neutral detergent fiber (NDF) and acid detergent fiber (ADF) in the outer weathered layer when alfalfa hay was stored outdoors (Collins et al., 1987; Russell et al., 1990; Harrigan and Rotz, 1994; Shinners et al., 2009). In most situations, NDF and ADF were 4% and 3%, respectively, less concentrated in net wrapped round bales compared to twine wrapped bales (Russell et al., 1990; Harrigan and Rotz, 1994; Shinners et al. 2009). In addition, the concentration of the fiber components resulted in a greater reduction in digestibility for twine wrapped bales compared to net wrapped bales (Collins et al., 1987; Huhnke, 1987; Russell et al., 1990; Shinners et al., 2009).

Historically, large round bales were primarily packaged with sisal or plastic twine. More recently, net wrap has gained popularity due to a 57% decrease in time required to wrap and a 65% reduction in DM loss associated with wrapping (Shinners et al., 2009). Net wrap has also been found to have 5% to 7% greater DM retention compared to sisal or plastic twine wrapped bales (Russell et al., 1990; Shinners et al., 2009). In an effort to further reduce DM and forage quality losses, an additional wrap-type was developed. B-Wrap® (Ambraco Inc., Dubuque, IA) is made from a microscopic pore material that is held in place with net wrap. Early prototypes of B-Wrap® showed similar DM losses to bales stored indoors (2%) compared to net wrap bales stored outdoors (12%), and NDF and ADF were less concentrated in bales wrapped with B-Wrap® (Shinners et al, 2013). However, a consideration with any new product is cost. The estimated cost per large round bale when wrapped with B-Wrap® is $8.33, compared to net wrap and twine with estimated costs of $1.17 and $1.00 per bale, respectively. Therefore, in addition to evaluating the efficacy of B-Wrap® in long-term outdoor storage, the economics of using this product are also needed.

In addition to advances in wrap-type technology, reduced-lignin alfalfa has become commercially available. Previous research found reduced-lignin alfalfa had increased *in vitro* dry matter digestibility (IVDMD), *in situ* rumen digestibility, and *in vitro* neutral detergent fiber digestibility (IVNDFD) when compared to reference alfalfa varieties (Guo et al., 2001; Reddy et al., 2005; Mertens and McCaslin, 2008; Weakley et al., 2008; Undersander et al., 2009; Getachew et al., 2011; Grev et al., 2017). However, little is known about the impact of outdoor storage of reduced-lignin alfalfa hay. It has been suggested that a reduction in lignin may result in hay being more susceptible to the effects of weathering. Therefore, the objectives of this research were to evaluate time required to wrap large round bales, determine changes in DM and forage quality, and examine the economics of reduce-lignin and reference alfalfa hay wrapped in twine, net wrap and B-Wrap® while in long-term, outdoor storage.

MATERIALS AND METHODS

In April 2016, two alfalfa cultivars were seeded into a prepared seedbed at a rate of 18.7 kg ha^{-1} in Otsego, Minnesota. Soil was a combination of an Angus-Le Sueur complex (1 to 6% slopes) and a Cordova loam (0 to 2% slopes), and soil fertility was amended to meet recommendations for alfalfa hay production according to University of Minnesota fertility guidelines (Kaiser et al., 2011). The two cultivars included reduced lignin (‘54HVX41’, Forage Genetics, Napa, ID) and reference (‘WL355.RR’, W-L Alfalfa, Ozark, MO) alfalfas. These cultivars were previously evaluated and determined to different in acid detergent lignin (ADL) and NDF digestibility (NDFD48), but similar in crude protein (CP) and NDF concentrations.

Hay was harvested from first cutting alfalfa on 7 June 2017 at the early bud stage (Kalu and Fick, 1981). Forage was cut, raked, and baled using best management practices designed to minimize leaf loss and optimize forage quality (Digman et al., 2011). Hay was baled into 1.22 by 1.50 m large round bales (John Deere 459, Moline, Illinois), and were identified using cattle ear tags manually attached at the time of baling. This cutting yielded 24 bales; 12 bales each of reduced-lignin and reference alfalfa. Within each alfalfa cultivar, four replicates were bound with each wrap-type including plastic twine (Case IH, Racine, WI), net wrap (Ambraco Inc., Dubuque, IA), and B-Wrap® (Ambraco Inc., Dubuque, IA). All wrap-types were applied according to manufacturer guidelines. Twine bound bales received six wraps on each end with 5 cm spacing, net wrap bales had 2.2 revolutions applied, and B-Wrap® had a total of four revolutions applied with one revolution of net wrap, followed by one revolution of B-Wrap®, and finally two revolutions of net wrap. All bales were stored outdoors on wood pallets, on the rounded side, with a small space between each bale.

During harvest, three trained observers recorded the time required to wrap each large round bale. Using stopwatches, time started when the tractor paused to wrap the bale and ended when the bale was ejected from the baler. Time to wrap was then averaged for each round bale. At the time of harvest and every 90 days (±3 days) for 365 days, individual bale weights were recorded using a calibrated platform scale (Weigh-Tronix, Fair-mount, MN, PS2000). Six stratified hay cores, three from each rounded side, were taken with a 47-cm hay probe (Penn State Forage Sampler, University Park, PA) from each bale. Hay cores were stratified into the outer 0 to 15 cm and the inner 16 to 47 cm. Hay cores within a bale and strata were combined. Immediately after each sampling event, all core holes were plugged with 3.6 cm cork stoppers (Widget Co., Houston, TX). To maintain the integrity of the B-Wrap®, duct tape (Gorilla Tape, Cincinnati, OH) was used to seal the cork stoppers.

All hay core samples were dried in a forced-air oven at 60°C for 48 h to determine DM then ground through a 6-mm screen in a Wiley mill (Thomas Scientific, Swedesboro, NJ) followed by a 1-mm screen in a Cyclotec (Foss, Eden Prairie, MN). Ground samples were mixed thoroughly, and subsamples were analyzed for nonstructural carbohydrates (NSC) by a commercial forage testing laboratory (Equi-Analytical, Ithaca, NY). Starch and water-soluble carbohydrates (WSC) were measured using techniques described by Hall et al. (1999) and NSC were estimated as the sum of WSC and starch (Longland and Byrd, 2006). Samples were then analyzed by near infrared reflectance spectroscopy (NIRS; Model DA 7200; Perten Instruments, Springfield, IL) with calibration equations developed in Minnesota to estimate CP, NDF, ADF, ADL and NDFD48. The standard error of cross validation was 1.63, 3.08, 2.21, 1.98 and, 2.64, respectively, for CP, NDF, ADF, ADL and NDFD48, while the R^2 was 0.93, 0.95, 0.93, 0.98 and, 0.87, respectively. Forage quality parameters from the NIRS analysis were used to calculate relative feed value (RFV; Rohweder et al., 1978). To determine the value of each bale, dollar per RFV point was calculated from a Minnesota quality-tested hay auction (Sauk Centre, MN; 2 May 2019). This price ($1.28 per RFV) was then used to calculate an individual bale value, less the expense of the bale wrap-type in excess of twine wrap at harvest. These costs were $0.17 and $7.33 for Net wrap and B-Wrap®, respectively. To determine the DM on a whole bale basis, the volume of the outer 15 cm of a 1.22 by 1.5 round bale was calculated and the proportion of the total was determined. The bale DM was then calculated as a weighted average of the outer 15 cm accounting for 44% and the remaining of the bale as 56%.

Data were analyzed using the MIXED procedure of SAS (version 9.4; SAS Institute Inc., Cary, NC) as a randomized complete block design. Individual bales were the experimental unit, and statistical significance was set at $P \leq 0.05$. Response variables included wrap time, bale moisture, bale weight (wet weight), bale DM, CP, NSC, NDF, ADF, ADL, NDFD48, and bale value (in dollars). Bale moisture was log transformed to meet analysis of variance assumptions then back transformed for presentation. For the response variable wrap time, the model included the wrap time as a fixed effect and the bale replicate as a random effect. For response variables DM, bale weight (kg), bale DM (kg), bale moisture, CP, NDF, ADF, NSC, ADL, and NDFD48 models included storage length, alfalfa cultivar, wrap-type, storage length × cultivar, storage length × wrap-type, and storage length × wrap-type × cultivar interaction as fixed effects. Random effects included replicate, and repeated measures included storage length. Results presented for bale moisture and forage quality included only the outer 0 to 15 cm layer, due to minimal differences observed in the 16 to 47 cm layer. Results presented for bale weight, bale DM, and bale value will be presented as a whole bale. For significant effects, means separations were performed using Tukey's HSD test.

RESULTS AND DISCUSSION

WEATHER. Monthly precipitation during the 365-day storage period was below the 30-year historical average except for August 2017, October of 2017, and February 2018, where precipitation was above the historical average (Figure 1). Air temperature was near the historical average, with the exception of February 2018 which was colder than anticipated (Figure 1).

WRAP TIME. The time required to wrap each bale was different based on wrap-type ($P < 0.01$; Table 1). Twine required the most time to wrap a bale (56 seconds) compared to B-Wrap® (28 seconds) and net wrap, which required the least time (18 seconds). These values agree with those previously reported. The time required to wrap bales in twine ranged from 25 to 75 seconds and for net wrapped bales, between 6 to 25 seconds (Busse, 1984; Anstey and Ardueser, 1991; Dodd, 1991; Taylor et al., 1995; Shinners et al., 2009). This is the first reported wrapping time for B-Wrap®. The range of times reported are likely due to bale size, wrapping window chosen to measure, number of wrap rotations required or used, operator skill level, and advancements in equipment automation.

Outer Layer Bale Moisture. The bale moisture concentration of the outer layer (0 to 15 cm) was not affected by alfalfa cultivar ($P = 0.16$). Moisture concentration of the outer layer (0 to 15 cm) was affected by the interaction of wrap-type and storage length ($P < 0.0001$; Figure 2). All bales began the storage period at a similar moisture of 9.3%. Samples were collected every 90 days (±3 days), and starting at day 90, bales wrapped in twine and net wrap had a greater moisture concentration compared to bales wrapped in B-Wrap® ($P < 0.0001$). However, twine and net wrapped bales were never different from one another during the storage period ($P \geq 0.05$). At 365 days, the moisture concentration of B-Wrap® bales was 9.1%, while net wrap and twine were higher at 27.2% and 26.6%, respectively ($P < 0.0001$).

Most previous research also found no difference in bale moisture in the outer layer when comparing twine and net wrapped bales (Bledsoe and Bates, 1992; Harrigan and Rotz, 1994; Russel et al., 1990; Taylor et al., 1994). However, Shinners et al. (2009) observed differences in the outer layer between twine and net wrapped bales; moisture was 21.5% and 17% in twine and net wrapped bales, respectively, after 144 days in outdoor storage. When evaluating a prototype, Shinners et al. (2013) found outdoor stored B-Wrap® bales had similar moisture concentrations as bales stored inside, and 6% to 10% less moisture than net wrap bales stored outdoors. These results suggest that B-Wrap® was better able to shed precipitation throughout the storage period compared to twine and net wrap.

Whole Bale Weight on a DM Basis. Whole bale weight on a DM basis was not affected by alfalfa cultivar ($P = 0.22$). Dry matter bale weight was affected by the interaction of wrap-type and storage length ($P < 0.0001$). Whole bale weight (DM basis) was not different among wrap types until 180 days of storage (Table 2). From 180 to 365 days of storage, B-Wrap® bales were consistently heavier compared to twine wrapped bales ($P \leq 0.05$). Dry matter bale weight of net wrapped bales tended to be similar to both twine and B-Wrap® bales throughout the storage period. Based on these values, change in DM bale weight from harvest through 365 days in storage was calculated. Twine bales lost 7% DM, net wrap bales lost 5% DM, and B-Wrap® bales maintained DM. These results agree with Taylor et al. (1994) and Harrigan and Rotz (1994) who found no differences between the DM loss in twine and net wrapped bales stored outside; however, Russell et al. (1990) found a 41% decrease in DM loss in net wrapped bales compared to twine wrapped bales stored outside. Shinners et al. (2013) evaluated a prototype of B-Wrap® and found DM loss of 2.1% while net wrap bales lost 11.2% DM. These results indicate that B-Wrap® reduced DM losses compared to net and twine wrapped bales stored outside.

CRUDE PROTEIN. The concentration of CP was not affected by alfalfa cultivar, wrap type or storage period ($P \geq 0.08$; Table 2). These results agree with Russell et al. (1990) and Harrigan and Rotz (1994) who found no differences in CP in net wrap and twine wrapped bales stored outdoors. When evaluating a prototype, Shinners et al. (2013) found minimal differences in CP between B-Wrap® bales and net wrap bales stored outside. However, Shinners et al. (2009) found changes in the retention of CP that tended to favor net wrap bales compared to twine wrapped bales. Generally, previous research has shown that CP tends to be an insoluble component of conserved forages including cases of in-field rainfall (Collins, 1982; Fonnesbeck et al., 1986) or soaking (Martinson et al., 2012) which agrees with the current study.

NONSTRUCTURAL CARBOHYDRATES. The concentration of NSC was not affected by alfalfa cultivar (P = 0.40). Nonstructural carbohydrates were affected by the interaction of wrap-type and storage length (P < 0.0001). However, NSC concentrations were not different between wrap types until 270 days in storage (Table 2). At 270 and 365 days of storage, NSC concentration was greater in B-Wrap® compared to twine wrapped bales, while net wrapped bales tended to be similar to both twine and B-Wrap® bales. Changes in NSC due to different wrap-types has not been previously reported; however, Collins et al. (1987) reported the total nonstructural carbohydrates (TNC) of large round bales stored outdoors covered and uncovered. They reported that bales stored outdoors uncovered lost 25% of the TNC compared to only a 4% loss of TNC for covered bales (Collins et al. 1987). Additionally, in early to late bud alfalfa, 2.5 cm of rainfall 24 hours after cutting hay reduced TNC to 4% (Collins, 1983). Martinson et al. (2012) found that soaking alfalfa bud hay in cold water for 60 minutes reduced NSC values from 9.3 to 5.5%.

Nonstructural carbohydrates were of interest in this study because these components are water soluble and help indicate moisture penetration. The results from the current research indicate B-Wrap® did not allow as much precipitation to penetrate the bale, which helped maintain NSC levels throughout the year-long storage period, compared to the other wrap types.

Natural Detergent Fiber. The concentration of NDF in the outer layer was affected by alfalfa cultivar (*P* = 0.03; data not shown). The NDF concentration was lower in reference alfalfa (52% DM) compared to the reduced-lignin alfalfa (55% DM). These results disagree with previously reported results that showed NDF was similar between reference and reduced-lignin alfalfa cultivars (Guo et al., 2001; Mertens and McCaslin, 2008; Grev et al., 2017).

Neutral detergent fiber was affected by the interaction of wrap-type and storage length (*P* < 0.0001). The concentration of NDF in the outer layer was not different until 180 days in storage (Table 2). Between 180 and 365 days of storage, B-Wrap® was lower in NDF compared to twin wrapped bales; net wrap bales had similar NDF concentrations compared to B-Wrap®. These results disagree with Harrigan and Rotz (1994) who found no difference in NDF concentration between bales stored outside in net wrap and twine. However, several researchers have found a 2 to 6% increase in NDF concentration of bales wrapped in twine compared to net wrap (Russell et al., 1990; Taylor et al., 1994; Shinners et al., 2009). Additionally, when evaluating a prototype, Shinners et al. (2013) found NDF concentrations were greater in net wrapped bales compared to bales wrapped in B-Wrap® and stored outdoors.

Acid Detergent Fiber. The concentration of ADF was not affected by cultivar (*P* = 0.07). Acid detergent fiber was affected by the interaction of wrap-type and storage length (*P* < 0.0001) Similarly to NDF, the concentration of ADF in the outer layer did not differ until 180 days of storage (Table 2). At 270 and 365 day of storage, ADF was lower in B-Wrap® bales compared to bales wrapped in net wrap and twine. These results agree with Harrigan and Rotz (1994) who found no differences in ADF concentration in the outer layer of bales wrapped with net wrap and twine. However, Russell et al. (1990) and Shinners et al. (2009) found ADF in the outer layer was concentrated in bales wrapped with twine compared to net wrap bales. In addition, when evaluating a prototype, Shinners et al. (2013) found ADF concentration was similar between B-Wrap® and net wrap when bales were stored outdoors.

Acid Detergent Lignin. Acid detergent lignin differed between the alfalfa cultivars (*P < 0.0001*). The reference alfalfa had a higher ADL (7.2%) compared to the reduced-lignin alfalfa (6.6%), which is equivalent to a 9% reduction in lignin (data not shown). These results are in agreement with previously reported ADL concentrations for both cultivars (Mertens and McCaslin, 2008; Undersander et al., 2009; Grev et al., 2017).

Acid detergent lignin was affected by the interaction of wrap-type and storage length (*P* < 0.007); however, it was only different at 270 days in storage. At this time, B-Wrap® had a lower ADL concentration compared to bales wrapped in net wrap and twine (Table 2). These results disagree with Russell et al. (1990) who reported lower ADL concentrations in the outer layer of bales wrapped in net wrap compared to twine (1990).

Neutral Detergent Fiber Digestibility. The NDFD48 of the alfalfa cultivars did not differ (*P* = 0.87). These results disagree with previous reports indicating 3% to 26% greater NDFD48 in reduced-lignin alfalfa compared to reference cultivars (Mertens and McCaslin, 2008; Weakley et al., 2008; Undersander et al., 2009; Li et al., 2015). NDFD48 was affected by the interaction of wrap-type and storage length (P < 0.0001). At each sampling point post-harvest, except 270 days, B-Wrap® resulted in a higher NDFD48 compared to bales wrapped in net wrap and twine (Table 2). These results disagree with Russel et al. (1990) and Shinners et al. (2009) who found increased *in vitro* digestible DM and *in vitro* true digestibility, respectively, in the outer layer of bales wrapped in net wrap compared to twine wrap. Shinners et al. (2013) tested a B-Wrap® prototype and found that digestible dry matter (DMD) was similar between bales wrapped in B-Wrap® compared to bales wrapped in net wrap and stored both indoors and outdoors.

RELATIVE FEED VALUE. Relative feed value was not affected by alfalfa cultivar (P = 0.91). This was anticipated as RFV is an index of forage quality accounting for concentrations of NDF and ADF (Rohweder et al., 1978). Although NDF in the current study was different among the cultivars, there were no differences in ADF which resulted in a similar RFV.

Relative feed value was affected by the interaction of wrap-type and storage length (P < 0.0001). At the time of harvest, net wrapped bales had higher RFV compared to B-Wrap® and twine bound bales; however, the research team is unable to explain the reason for this difference (Table 2). Differences in RFV were not observed until 270 and 365 day of storage. At these time points, bales wrapped in B-Wrap® had greater RFV compared to twine wrapped bales. Net wrap was similar to twine at 270 days and to both B-Wrap® and twine at 365 days in storage These results agree with Harrigan and Rotz (1994) who found no differences in RFV between bales wrapped in net wrap or twine; however, they did observe a 14-

point drop in RFV when bales were stored outdoors compared to indoors. Additionally, when evaluating an early prototype, Shinners et al. (2013) found the RFV of B-Wrap® bales stored outdoors was similar to bales stored indoors and to net wrapped bales stored outdoors.

Within previous research reports, there has been high variability in changes of DM and forage quality loss across studies. There are several possible explanations for the deviation in the current study including, but not limited to, storage methods (i.e. on pallets), regional climate and variation in monthly precipitation, or moving and sampling bales every 90 days.

BALE VALUE. Bale value was not affected by alfalfa cultivar ($P = 0.10$). Bale value was affected by the interaction of wrap-type and storage length ($P < 0.0001$). The bale value was different between the wrap-types at harvest (Figure 3) due to the unexplained higher RFV reported for the net wrapped bales (Table 2). Differences in bale value were observed at 180 and 270 days in storage. At these times, the value of B-Wrap® bales were greater than net wrap and twines wrapped bales by \$11.22 and \$13.64 and \$11.76 and \$17.27, respectively. After 365 days of storage, there were no differences between wrap types.

The cost of a wrap type is a common concern for producers. The estimated cost per large round bale when wrapped with B-Wrap® is \$8.33, compared to net wrap and twine with estimated costs of \$1.17 and \$1.00 per bale, respectively. However, the ability of B-Wrap® to shed precipitation and maintain RFV, commonly used to price forage, appears to offset the product cost after 90 days of storage. Both hay and livestock producers can use this information to influence decisions related to selecting a wrap type.

CONCLUSIONS

Twine required the most time to wrap a bale (56 seconds) compared to B-Wrap® (28 seconds), then net wrap (18 seconds). After 365 days in outdoor storage, DM losses were 7% for twine wrapped bales, 5% for net wrap bales, while B-Wrap® bales maintained DM. Additionally, the moisture content of the outer layer of B-Wrap® bales was similar throughout the 365 days of storage, with the moisture content of both net and twine wrapped bales increased. Changes in forage quality were commonly observed at ≥180 days of storage with a dilution of NSC and a concentration of insoluble fiber components including NDF and ADF. Additionally, NDFD48 and RFV tended to be greater for B-Wrap® bales compared to net and twine wrapped bales starting at 90 and 270 day of storage, respectively. The conservation of RFV lead to differences in whole bale value observed at 180 and 270 days in storage where B-Wrap® bales were worth approximately $10 more per bale compared to net and twine wrapped bales. B-Wrap® appears to better shed precipitation resulting in a conservation of DM and forage quality in bales stored outdoors for 365 days compared to net and twine wrap.

FUTURE RESEARCH

Based on these results, future research should investigate if the differences between wrap types influence livestock preference, intake, and hay waste when feeding bales stored outdoors for long periods of time. Additional research should focus on the comparison of modern B-Wrap® bales stored outdoors compared to bales stored indoors.

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Figure 1.1 Total monthly precipitation (cm; A), average air temperature (°C; B), and 30-year average throughout the outdoor round bale storage period of June 2017 to June 2018.

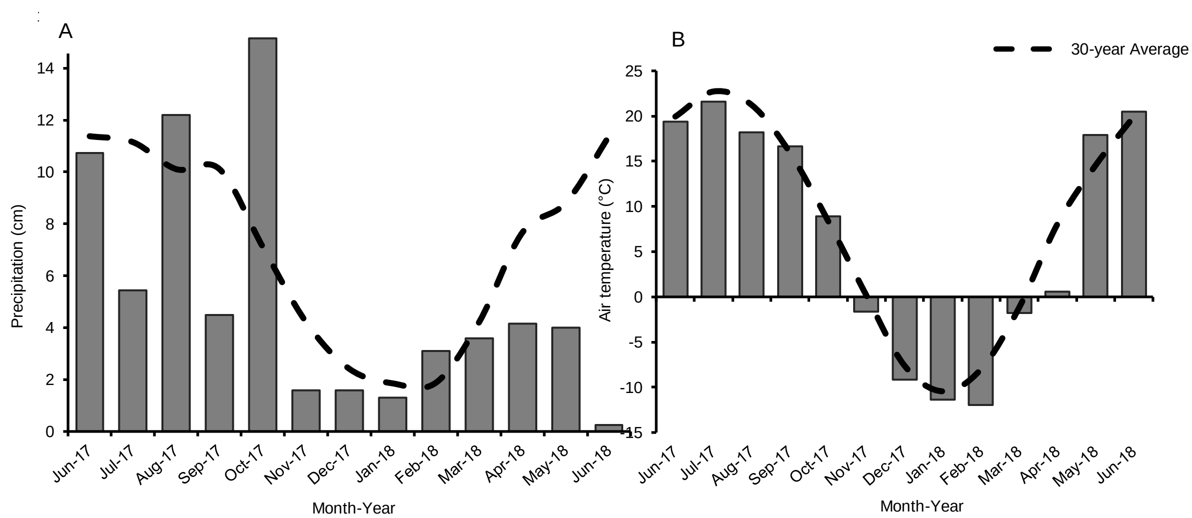
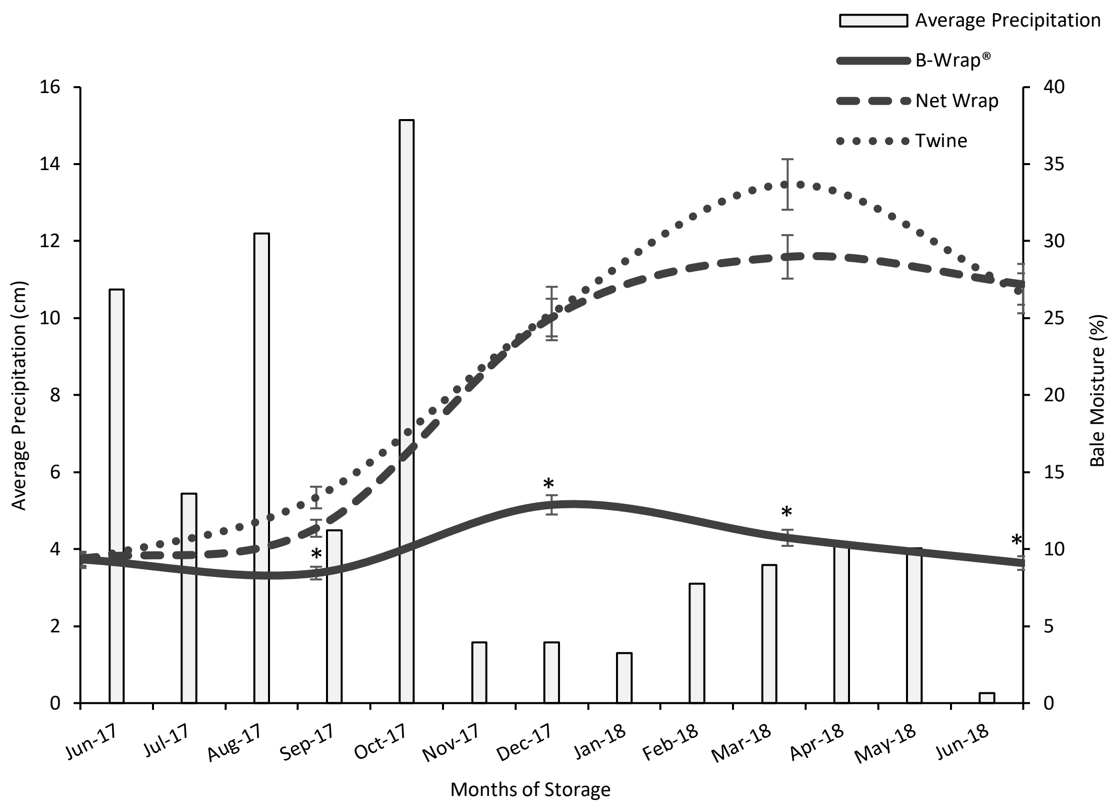
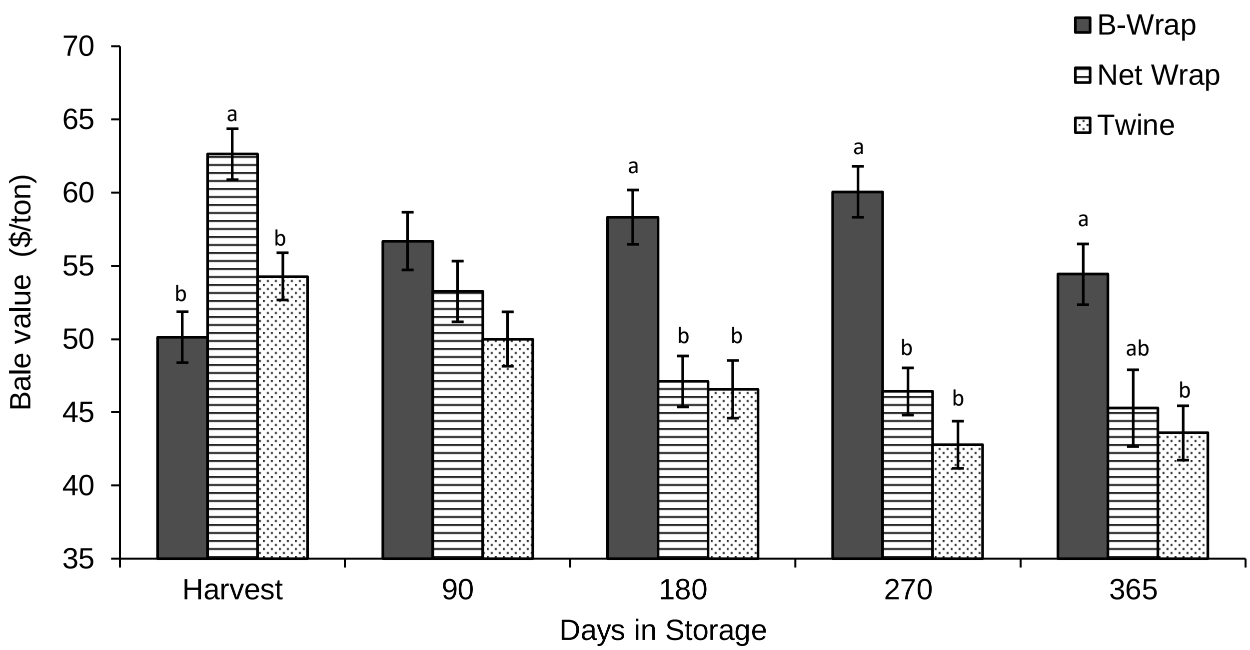


Figure 1.2 Monthly total precipitation (cm) and bale moisture (%) in the 0-15 cm layer of alfalfa large round bales stored outdoors and wrapped in twine, net wrap, and B-Wrap® for 365 days (June 2017 to June 2018).



* Means within a storage period differ ($P < 0.0001$)

Figure 1.3 Hay value ($ per ton) of alfalfa hay stored outside for 365 days and wrapped in either twine, net wrap, and B-Wrap®.



[ab] Means within a storage period differ ($P < 0.05$)

Table 1.1 Time required to wrap individual 1.22 by 1.50 m large round bales with net wrap, B-Wrap®, or twine.

Wrap type	Time	SEM
	(s)	
Net	18[a]	0.62
B-Wrap®	28[b]	0.67
Twine	56[c]	0.55

[abc] Means without common superscripts differ (*P* < 0.0001)

Table 1.2 Bale weight and forage quality of alfalfa hay stored outdoors wrapped in twine, net or B-Wrap® for 365 days.

Storage time	Wrap Type	Bale Weight (wet basis)	Bale Weight (DM)	RFV	CP	NSC	NDF	ADF	ADL	NDFD48
		Kg			% DM					% NDF
		Whole Bale			Outer Layer					
Harvest	Twine	361	330	117^{a}	14.3	12.8	50.0	33.3	6.3	38.8
	Net	370	335	132^{b}	15.7	13.0	45.6	30.1	6.3	42.0
	B-Wrap®	371	336	118^{a}	14.5	12.2	50.4	33.8	6.4	40.1
90 days	Twine	366	330	109	14.5	10.0	55.2	37.4	6.8	32.4^{a}
	Net	378	340	111	14.2	10.0	54.3	36.8	6.8	33.5^{a}
	B-Wrap®	379	345	116	14.9	11.2	49.8	33.8	6.5	40.7^{b}
180 days	Twine	368	307^{a}	107	14.8	8.1	56.4^{ab}	39.2^{ab}	7.3	31.9^{a}
	Net	377	317^{ab}	108	14.3	8.4	58.8^{a}	39.8^{a}	7.3	31.9^{a}
	B-Wrap®	384	340^{b}	116	14.9	10.1	50.0^{b}	34.4^{b}	6.7	39.4^{b}
270 days	Twine	375	298^{a}	101^{a}	15.2	7.3^{a}	58.5^{a}	40.3^{a}	7.3^{a}	33.7^{a}
	Net	382	312^{a}	106^{ab}	14.4	8.9^{ab}	57.8^{a}	39.3^{a}	7.4^{a}	32.0^{a}
	B-Wrap®	386	348^{b}	118^{b}	15.2	10.9^{b}	48.6^{b}	33.3^{b}	6.4^{b}	42.3^{a}
365 days	Twine	373	308^{a}	96^{a}	14.6	8.0^{a}	62.9^{a}	43.9^{a}	7.8	25.3^{a}
	Net	379	318^{ab}	104^{a}	13.5	9.3^{ab}	58.3^{a}	40.5^{a}	7.8	29.8^{a}
	B-Wrap®	385	345^{b}	121^{b}	15.2	11.7^{b}	48.5^{b}	33.8^{b}	6.9	39.3^{b}

[ab] Means within a column and storage time without common superscript differ ($P < 0.05$)

CHAPTER 3

Effect of Wrap-type on Cattle Preference and Waste

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CHAPTER SUMMARY

Large round bales of hay stored uncovered outdoors can result in changes in forage quality and growth of mold. These factors can influence dry matter intake (DMI) and hay waste by livestock animals. The objective of this study was to evaluate cattle preference and hay waste of large round bales wrapped with plastic twine, net wrap, and B-Wrap after long-term, outdoor storage. Large round bales of alfalfa (*Medicago sativa L*) hay (n=24) were stored outdoors for 15 months in plastic twine, net wrap, and B-Wrap. After the storage period, round bales were fed in a switchback design to 18 Angus cow-calf pairs. Pairs had *ad libitum* access to three round bales, one of each wrap-type, in individual feeders for 48-hour periods (n=8). Feeders were weighed and waste surround feeders was collected at 24 and 48 h to calculate DMI and hay waste. Statistical significance was set at $P < 0.05$. Total DMI, and DMI during the first 24 hours, were greater in B-Wrap bales compared to twine wrapped bales indicating the cattle preferred hay wrapped in B-Wrap. Net wrapped bales resulted in similar forage quality and DMI to both B-Wrap and twine wrapped bales. However, no difference in hay waste were observed between the wrap-types. These results

confirm wrap-type influenced forage quality and mold counts in outdoor stored hay, which in turn impacted cattle preference at the time of feeding.

INTRODUCTION

Large round bales are a common way to harvest, store and feed livestock hay throughout the United States. However, the quality of large round bales is known to deteriorate during outdoor storage. This deterioration is mostly concentrated to the outer layer which is most exposed to weather (Belyea et al., 1985; Russell et al., 1990; Collins et al., 1987; Shinners et al., 2009 and 2013). Specifically, moisture from rainfall and snow can result in the loss of soluble nutrients, the subsequent concentration of insoluble plant fibers, the growth of mold, and repugnant odors (Russell et al., 1990; Collins et al., 1987; Scudamore et al., 1998; Shinners et al., 2009). These factors can reduce livestock dry matter intake (DMI) and result in feeding losses (Belyea et al., 1985; Russell et al., 1990; Undi et al., 1996).

Several storage methods have been studied to determine their impact on DMI and associated livestock feeding losses. Belyea et al. (1985) determined round bales stored outdoors and covered had less storage and feeding losses compared to bales stored outdoors uncovered. Cattle wasted 12% to 15% of covered round bales compared to 25% of uncovered round bales (Belyea et al., 1985). Additionally, Russell et al. (1990) found that outdoor stored round bales wrapped in net wrap resulted in 16% to 25% greater DMI by sheep compared to round bales wrapped with twine. More recently, Shinners et al. (2013) evaluated cattle preference after round bales were stored in different wrap-types, processed, and fed in bunkers. They found that shredded round bales wrapped with B-Wrap were preferred over net wrapped bales stored outdoors without cover and had equal preference to net wrapped bales stored indoors (Shinners et al., 2013). However, research is needed to evaluate hay waste and cattle preference when feeding unprocessed, or whole, large round bales harvested and wrapped with different wrap-types. Therefore, the objectives of this research were to determine hay waste and cattle preference of large round bales wrapped with plastic twine, net wrap, and B-Wrap after long-term, outdoor storage.

MATERIALS AND METHODS

First cutting alfalfa hay was harvested on 7 June 2017 at the early bud stage (Kalu and Fick, 1981) in Otsego, MN. The alfalfa included two cultivars, reduced lignin ('54HVX41', Forage Genetics, Napa, ID) and reference ('WL355.RR', W-L Alfalfa, Ozark, MO). Forage was cut, raked, and baled using best management practices designed to minimize leaf loss and optimize forage quality (Digman et al., 2011). Hay was baled into 1.22 × 1.50 m large round bales (John Deere 459, Moline, Illinois) and yielded 24 bales; 12 bales of each cultivar. Within each alfalfa cultivar, four replicates were bound with each wrap-type. Wrap types included plastic twine (Case IH, Racine, WI), net wrap (Ambraco Inc., Dubuque, IA), and B-Wrap (Ambraco Inc., Dubuque, IA). All wrap types were applied according to manufacturer guidelines, and bales were stored uncovered, outdoors, on wood pallets for 15 months prior to feeding. The 15-month storage period ended on 1 September 2018.

Round bales used in the current study were previously utilized in a research trial investigating the effect of wrap-type on dry matter (DM) loss and forage quality of round bales in outdoor storage (Reiter et al., 2019). After treatment difference were confirmed during the storage period, round bales were transported to the Rosemount Research and Outreach Center in Rosemount, MN. Starting on 3 October 2018 round bales were fed to cattle to determine the effect of wrap-type on cattle preference and hay waste.

Immediately prior to feeding, round bales were weighed using axel weigh pads (Locosc, Ningbo, China) and cored four times with a 47-cm hay probe (Penn State Forage Sampler, University Park, PA) to determine dry matter (DM), forage quality, and mold and yeast counts. Hay core samples were dried in a forced-air oven at 60°C for 48 h to determine DM. Samples were then ground through a 6-mm screen in a Wiley mill (Thomas Scientific, Swedesboro, NJ) followed by a 1-mm screen in a Cyclotec (Foss, Eden Prairie, MN). Ground samples were mixed thoroughly, and subsamples were analyzed using near infrared reflectance spectroscopy (NIRS) to determine crude protein (CP), ether extract, crude fiber, ash, and NFE (Dairy One, Ithaca, NY). Total digestible nutrients (TDN) was then calculated (Weiss et al., 1992). Additionally, samples were scanned using NIRS (Model DA 7200; Perten Instruments, Springfield, IL) with calibration equations developed in Minnesota to estimate CP, neutral detergent fiber (NDF), acid detergent fiber (ADF), neutral detergent fiber digestibility (NDFD48), and acid detergent lignin (ADL). The standard error of cross validation was 1.63, 3.08, 2.21, 2.64, and 1.98, while the R^2 was 0.93, 0.95, 0.93 and 0.87 and, 0.98 for CP, NDF, ADF, NDFD48 and ADL, respectively. Relative forage quality (RFV) was then calculated (Rohweder et al., 1978).

Hay core subsamples to determine mold and yeast counts were analysis by a commercial lab (DHIA Laboratories, Sauk Centre, MN). In brief, mold and yeast counts were determined through pour plate methodology using potato dextrose agar and peptone buffer. A total of 50 g of test material was diluted with 45 mL of peptone buffer. Serial dilutions were made to yield four dilutions, which were plated in peptone buffer. Plates were incubated in an upright position at 25°C to 27°C for 5 to 7 days. Mold and yeast colonies were then counted and expressed as CFU/g.

All experimental procedures were conducted according to those approved by the University of Minnesota Committee on Animal Use and Care (1808-36268A). Eighteen Angus cow-calf pairs were housed in a 24 × 34 m cement pen, which included a 10 × 34 m covered area. Calves were approximately 33 ± 11 days old at the initiation of the trial. Throughout the trial, the pairs had *ad libitum* access to water and loose mineral (Rain and Wind All Season, Purina, St. Louis, MO). Individual cow bodyweight (BW) and body condition score (BCS; Spitzer, 1986) were recorded at the start and conclusion of the 17-day trial. Round bales were fed in a switchback design where periods were blocked by alfalfa cultivar. Bales were rotated in a repeating Latin square design so that the wrap-type locations were not repeated in consecutive periods. Bales were individually fed in 2.4 ×1.1 m skirted round bale feeders (Priefert, Mount

Pleasant, TX). All feeders were retrofitted with a welded bottom plate to facilitate moving and weighing the bales once fed. Feeders were placed approximately 6.7 m apart in the covered area of the pen and cattle were allowed *ad libitum* access to all feeders. For each 48-hour period (n=8), three round bales, one from each wrap type within an alfalfa cultivar, were fed. At hours 24 and 48, the entire feeder was weighed using axel weigh pads (Lococs, Ningbo, China) to determine DMI. No other feedstuffs were offered during the 17-day trial; however, a bedding pack of chopped straw was maintained in the uncovered section of the pen.

Each day, hay waste was collected from the perimeter of the feeders. Hay waste was defined as hay on the ground outside of the feeders. After hay waste was removed, the area around each feeder was scraped clean by hand then power swept using a skid loader broom attachment (SE Series Hopper Broom, Spartan Equipment, Joppa, MD) to minimize contamination with manure, although contamination was inevitable. Therefore, contaminate hay waste was rinsed with water to remove manure before drying. All hay waste was dried in a forced-air oven at 60°C until a constant weight was achieved to determine DM. After 48 hours, hay remaining in the feeders (orts) was removed, and new bales were fed. Percent hay waste was calculated as the total amount of daily hay waste divided by the amount of hay fed, minus orts (Martinson et al., 2012). Dry matter intake was calculated as the amount of hay fed, minus orts and total hay waste, and was used to determine preference.

Forage quality, DMI and hay waste data were analyzed using the MIXED procedure of SAS (version 9.4; SAS Institute Inc., Cary, NC). Individual bales were the experimental unit, and statistical significance was set at $P \leq 0.05$. Forage quality response variables included bale moisture content, CP, NDF, ADF, ADL, NDFD48, TDN, RFV, and mold and yeast counts. Bale moisture content and mold and yeast counts were log transformed to meet analysis of variance assumptions; data were back transformed for presentation. Forage quality response variable models included alfalfa cultivar, wrap-type, period, and alfalfa cultivar × wrap-type interaction as fixed effects, while bale replicate was included as a random effect. The model for response variables hay waste and DMI included wrap-type, feeder placement, and period as fixed effects at each collection time, 24 and 48 h. Initial bale DM was evaluated as a covariate for response variables associated with waste and remained in the model when significant. For categorical effects (e.g. wrap-type), means separations were performed on significant effects using Tukey's HSD test. To assess the relationship between DMI and forage quality, partial Pearson correlation coefficients were calculated between DMI and the forage quality for mold counts using the REG procedure of SAS (version 9.4; SAS Institute Inc., Cary, NC). Changes in animal BW and BCS over the experimental period were evaluated using a two sample t-test using PROC TTEST in SAS (version 9.4; SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

Weather

Average daily temperatures and precipitation for the duration of the experiment are shown in Fig. 1. Generally, daily average air temperatures were below the 30-year average except on October 3rd, 4th and 9th. There were seven rainfall events during the experimental period; however, all bales were fed under cover, so rainfall events had a minimum impact on results. Further, calves were provided a creep area undercover that was bedded with straw to lessen the impact of poor weather on calf health.

Bale Moisture

Bale moisture did not differ between reference and reduced-lignin alfalfa (14.7%; $P = 0.37$). However, bale moisture was different between the wrap-types ($P = 0.01$; Table 1). Round bales stored in net wrap had greater moisture content (16.4%) compared to B-Wrap bales (12.8%), while twine bales were intermediate (14.9%). Previous work has shown that B-Wrap and other breathable film wraps shed precipitation better compared to net and twine wrap (Shinner et al., 2013; Reiter et al., 2019). However, other researchers have observed no differences in moisture content between twine and net wrap (Harrington and Rotz, 1994; Taylor et al., 1995) after outdoor storage.

Bale Dry Matter

Initial bale weight (DM) was different between the wrap-types after 15 months of outdoor storage (P = 0.007; Table 2). Bales wrapped in B-Wrap had a greater mass (333 kg DM) compared to bales wrapped in twine (299 kg DM) while net wrap was similar to both (309 kg DM). The differences in bale weight were due to DM losses observed during the 15-month storage period. At the start of the outdoor storage period all bales had a similar weight; however, DM losses were different between wrap-types (Reiter et al., 2019). Many researchers have determined that twine wrapped bales experience greater DM losses due to external moisture penetration than net wrapped bales (Russell et al., 1990; Shinners et al., 1990). While Shinners et al. (2013) and Reiter et al. (2019) found that moisture concentration in hay stored in B-Wrap was 36% less compared to net wrap, and 65% to 66% less compared to net and twine wrapped, respectively, bales stored outside. These results indicate B-Wrap repels environmental moisture and conserves DM during outdoor storage.

Forage Quality

Alfalfa cultivar did not affect forage quality ($P > 0.05$). With the exception of ADL and NDFD48, these results were anticipated as others have found similarities in CP, NDF, and ADF between reduced-lignin and reference alfalfa cultivars (Getachew et al., 2011; Li et al., 2015; Grev et al., 2017; Peterson et al., 2018). Although other researchers have found differences in ADL and NDFD48 between reduced-lignin and reference alfalfa cultivars at harvest (Mertens and McCaslin, 2008; Weakley et al., 2008; Undersander et al., 2009; Li et al., 2015; Grev et al., 2017), no one has investigated whole bale differences between cultivars after long-term, outdoor storage. Reiter et al. (2019) found no interaction between alfalfa cultivar and storage length while most of the observed differences were from the interaction of storage length and bale wrap-type. These results suggest that forage quality differences observed between reduced-lignin and reference alfalfa at harvest may be lost after long-term outdoor storage. Future research should continue to investigate this relationship and the impact on livestock performance.

The concentrations of CP, ADL, ADF, and NDFD48 were similar across wrap types (*P* > 0.05; Table 1). These results were expected for CP as previous researchers have found no differences in CP concentration between alfalfa hay stored outdoors in different wrap-types

(Russell et al., 1990; Harrigan and Rotz, 1994; Shinners et al., 2013; Reiter et al., 2019). Few researchers report ADL concentration; therefore, there have been conflicting findings of ADL concentrations during outdoors storage. Russell et al. (1990) finding greater concentrations in twine wrapped bales compared to net wrapped bales, while Reiter et al. (2019) found few differences in ADL concentration between twine, net wrap, and B-Wrap bales stored outdoors. The absence of differences in ADF were unexpected as previous researchers have found greater ADF concentrations in twine wrap (Russell et al., 1990; Shinners et al., 2009; Reiter et al., 2019) and net wrap (Reiter et al., 2019) alfalfa round bales stored outside. Additionally, Reiter et al. (2019) found greater NDFD48 was 24% to 35% greater in B-Wrap bales compared to net and twine wrapped bales, respectively, after 12 months of storage; however, Shinner et al. (2013) found no differences in the DM digestibility between B-Wrap net wrapped bales stored outside.

However, NDF was different between the wrap-types (*P* = 0.03). Neutral detergent fiber was greatest in bales wrapped in twine (49%) compared to B-Wrap (46%), net wrap intermediary (48%; Table 1). These results agree with previous work that showed NDF values tend to be higher, or more concentrated, in twine and net wrap bales compared to B-Wrap after storage outdoors

(Shinners et al., 2013; Reiter et al., 2019). Shinners et al. (2013) found an 8% increase in NDF in net wrapped bales compared to B-Wrap, while Reiter et al. (2019) found a 16% to 23% increase in NDF in net and twine wrapped bales. Forage quality of storage hay is important, as elevated NDF concentrations can limit DMI in cattle due to decreased palatability and increased rumen fill (Dado and Allen, 1995).

Wrap-type affected TDN (P = 0.02) where bales wrapped in twine (61%) had a lower TDN compared to B-Wrap (63%), while net wrap was similar to both (62%; Table 1). Similar results were observed by Shinners et al. (2013) who found greater TDN in breathable films and net wrap bales stored indoors compared to some net wrap stored outdoors (Shinners et al., 2013). However, TDN of 60 to 63% is consistent with alfalfa hay in early to mid-bloom and should meet the energy requirement for cows in early to mid-lactation (NRC, 2000).

Relative feed value was different between the wrap-types (P = 0.04), where it was highest in B-Wrap (130) compared to twine (118) and intermediary for net wrap (124; Table 1). Although the bales in the current study were stored outdoors for 15 months, RFV was still similar to alfalfa harvested between early bloom to late bloom (Dunham, 1988). Similarly, Reiter et al. (2019) and Shinners et al. (2013) reported higher RFV in bales wrapped in B-Wrap compared to twine and net wrap, and net wrap, respectively.

Mold and Yeast Counts

Mold counts differed between wrap-types (P < 0.0001). Twine and net wrap bales had the highest mold count at 7.1×10^6 and 4.7×10^6 CFU/g, respectively, while B-Wrap had lower counts at 4.8×10^4 CFU/g (Table 1). Several researchers have reported visual observations of mold growth in round bales stored outside; however, this is the first study to quantify the impact of wrap-type on mold quantity (Russell et al., 1990; Harrigan and Rotz, 1994; Shinners et al., 2009; 2010). Current recommendations for the maximum inclusion of mold in livestock rations indicate values of $< 5 \times 10^5$ CFU/g being considered safe, 5×10^5 to 1×10^6 CFU/g being relatively safe, $> 1 \times 10^6$ CFU/g should be fed with caution, and $> 5 \times 10^6$ CFU/g should not be fed to livestock (Adams et al., 1993). According to these recommendations, hay wrapped in B-Wrap and stored outdoors for 15 months was considered safe to feed livestock, hay wrapped in net wrap should have been fed with caution, and hay wrapped in twine wrap bales should not have be fed. However, no illnesses or adverse health issues were observed in cow-calf pairs throughout the experimental period.

Measuring mold in outdoor stored hay is important as mold content can influence DMI. When moldy hay was fed to steers, it resulted in a lower DMI and decreased rumen function (Mohanty et al., 1969). Additionally, dairy calves preferred hay with low ($< 2.0 \times 10^4$ CFU/g) amounts of mold compared to the high ($>1.4 \times 10^5$ CFU/g) and moderate moldy hays (8.5×10^4 CFU/g) consuming 27% to 60% less hay from moderate and high moldy hays, respectively (Undi et al., 1996). In the current study, DMI in the first 24 hours was negatively associated with the mold content of the hay ($r = -0.52$; $P = 0.02$).

There were no differences in yeast counts between the wrap-types (*P* = 0.07; Table 1). Yeast contamination is typically of concern in high moisture, fermented silage, and haylage but rarely in dried hays as moisture levels tend to be too low to support yeast growth (Kung, 2001: Muck and Shinners, 2001; Fulgueria et al., 2007). To our knowledge, there are no recommendations for the maximum inclusion of environmental yeast in ruminant diets. Although limited research has investigated the presence of yeast and the influence of hay contaminated with yeast on DMI, some yeast species (*Saccharomyces cerevisiae*) are under investigation as direct-fed microbial in ruminant diets (Keyser et al., 2007; Oetzel et al., 2007; Malik and Bandla, 2010). However, yeast species should be identified as environmental yeast during hay making and storage may differ from those being tested as direct-fed microbials.

Cow Bodyweight and Body Condition

Cow BW and BCS did not differ throughout the trial ($P \geq 0.20$). On average, cows weighed 692 ± 46 kg at the start of the experiment (3 October 2018) and weighed 711 ± 46 kg 17 days later when the trial ended. Average cow BCS (Spitzer, 1986) was 6.4 ± 0.3 at the start of the trial and 6.7 ± 0.4 at the conclusion. Due to the relatively short experimental trial, cows were not expected to have a changes gain in BW or BCS. Finally, cows consumed 2.5% BW per day in forage which is consistent with expected forage intake of beef cows consuming average to high quality forage in early to mid-lactation (Hibberd and Thrift, 1992; NRC, 2000).

Dry Matter Intake and Cattle Preference

Wrap-type affected DMI during the first 24 hours and total DMI (*P* = 0.02; *P* = 0.03, respectively), but not after 48-hours (*P* = 0.22*;* Table 2). During these times, cows consumed more hay from B-Wrap bales compared to twine bales. Net wrapped bales were always similar to the other wrap-types. These results agree with previous findings of greater DMI of bales stored in breathable films similar to B-Wrap (Shinner et al., 2013). However, Shinner et al. (2013) also observed differences in cattle DMI between hay stored outdoors, wrapped in breathable films and net wrap bales, then processed and fed to cattle. The absence of differences in DMI after 48 hours is likely a result of cows consuming a majority of the hay they preferred in the first 24-hours, then consuming the remaining hay more equally.

When examining how cows utilized the round bales, there were no differences in the amount of hay utilized expressed as a percent of DM fed throughout the study period (*P* > 0.05; Fig. 2). Mean total hay utilization was 68, 68 and 67% for twine, net wrap, and B-Wrap bales, respectively. The hay utilization is similar to Baxter et al. (1986) who found cows utilized an average of 70% of alfalfa-orchardgrass (*Dactylis glomerate L.*) round bales stored outside.

Hay Waste

There were no differences in hay waste collected at 24 hours, 48 hours, or total hay waste between the wrap-types (*P* = 0.55*;* Table 2). Mean total hay waste was 2.2, 2.5 and 2.9% in twine, net wrap and B-Wrap. Generally, hay waste in the current study was lower than expected for round bales stored outdoors. Previously reported hay waste ranged from 12% to 25% (Nelson et al., 1985; Belyea et al., 1985; Baxter et al., 1986). The lack of differences observed in hay waste could be a result of using the same bale feeder for all bales. Previous researchers found differences in hay waste between round bale feeder types (Buskirt et al., 2003; Sexten, 2011; Martinson et al., 2012; Moore and Sexten, 2015). Utilizing the same bale feeder combined with minimal differences between forage quality among wrap-types could be the driving forces for the similarities in hay waste.

Interestingly, hay waste was different between the 24- and 48-hour collection periods (P = 0.03). On average, hay waste in the first 24 hours (4.6%) was greater compared to the average waste collected at 48 hours (2.9%). Hay waste many have been greater in the first 24-hour period because cattle were observed “lifting and flipping” the outer layer of weathered hay out of the feeder in order to reach the interior of the bale. Additionally, researchers observed competition at the feeder containing the B-Wrap bales during the first 24-hour period. During this time, cattle would compete for head stalls at the feeder. Both of these behaviors are possible causes for the greater hay waste observed during the first 24-hours.

CONCLUSION

This study evaluated cattle preference and hay waste when fed hay stored outdoors and wrapped in twine, net wrap, and B-Wrap. After 15 months in outdoor storage, B-Wrap bales had lower amounts of NDF, greater values of TDN and RFV, and lower amounts of mold compared to twine tied bales. Total DMI, and DMI during the first 24 hours, were greater in B-Wrap bales compared to twine tied bales indicating the cattle preferred hay wrapped in B-Wrap. Net wrapped bales resulted in similar forage quality and DMI to both B-Wrap and twine wrapped bales. However, no difference in hay waste were observed between the wrap-types. These results confirm wrap-type influenced forage quality and mold counts in outdoor stored hay, which in turn impacted cattle preference at the time of feeding. These results will help producers make research-based decision related to harvesting, storing, and feeding hay to beef cattle.

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Figure 2.1 Daily and 30-year average air temperature (°C) and daily precipitation (cm) throughout experimental period (3 – 19 October 2018).

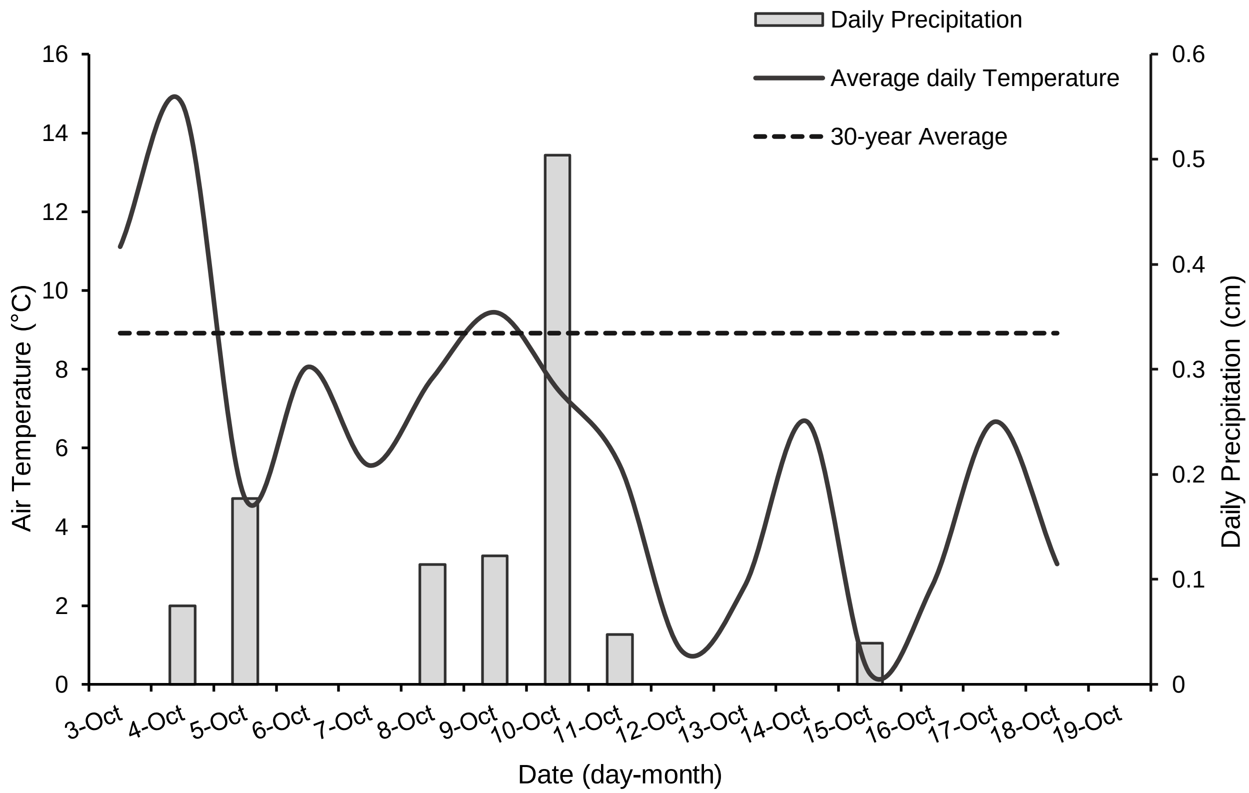

Figure 2.2 Hay utilization (% DM fed) by beef cows after 24 hours and 48 hours of access to alfalfa hay wrapped in twine, net and B-Wrap and stored outdoors for 15 months before feeding.

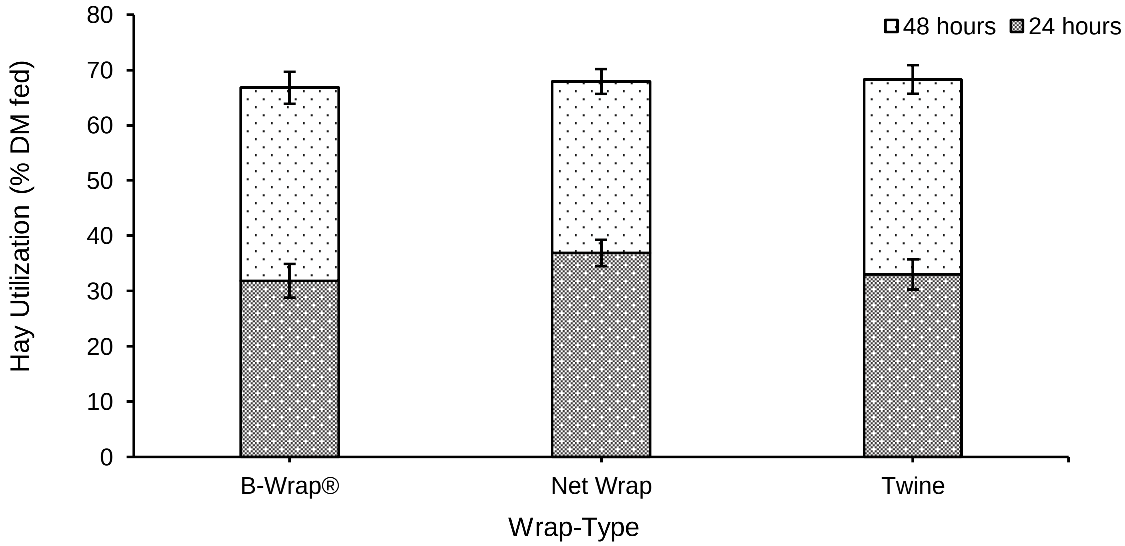

Table 2.1 Bale moisture, forage quality, and mold and yeast counts of alfalfa hay stored outdoors for 15 months and wrapped in twine, net, or B-Wrap.

	Wrap-Type			
	Twine	Net	B-Wrap	SEM
Moisture (%)	14.9[ab]	16.5[a]	12.8[b]	1.0
CP (% DM)	14.5	14.7	14.8	0.3
NDF (% DM)	49.3[a]	47.8[ab]	46.1[b]	0.7
ADF (% DM)	33.5	32.4	31.2	0.7
ADL (% DM)	6.0	6.0	6.4	0.2
NDFD48 (% NDF)	44.8	46.4	46.9	0.8
TDN (% DM)	61[a]	62[ab]	63[b]	0.5
RFV	118[a]	124[ab]	130[b]	2.8
Mold count (CFU/g)	7.1×10^{6} [a]	4.7×10^{6} [a]	4.8×10^{4} [b]	2.5
Yeast count (CFU/g)	1.5×10^{4}	6.0×10^{3}	2.6×10^{5}	3.3

[ab] Means within quality parameter without common superscripts differ ($P < 0.05$)

Table 2.2 Initial bale weight (DM, kg), hay waste (%), and dry matter intake (DMI, kg) of alfalfa hay stored outdoors for 15 months, wrapped in twine, net or B-Wrap and fed to beef cattle.

	Initial Bale Weight	Waste			DMI		
	Kg (DM)	% DM offered			Kg/cow		
Wrap-type		0 – 24 hr	24 – 48 hr	0 – 48 hr	0 – 24 hr	24 – 48 hr	0 – 48 hr
Twine	299	4.6	3.4	2.2	4.2[a]	6.4	10.7[a]
Net Wrap	309	4.5	2.8	2.9	5.8[ab]	5.5	11.4[ab]
B-Wrap	333	4.5	2.3	2.5	7.9[b]	5.5	13.4[b]
SEM	6.67	0.96	1.5	0.41	0.81	0.40	0.64

[ab] Means within a column without common superscripts differ ($P < 0.05$)