IMPROVEMENT IN STORED FORAGE UTILIZATION DURING FEEDING

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by
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**IMPROVEMENT IN STORED FORAGE UTILIZATION DURING FEEDING**

Presented by Wesley Alan Moore,

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and hereby certify that in their opinion it is worthy of acceptance.

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DEDICATION

To my parents, Keith and Carole Moore, who taught me hard work and dedication while developing my passion in science and beef cattle production.
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IMPROVEMENTS IN STORED FORAGE UTILIZATION DURING FEEDING

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Dr. Justin Sexten, Thesis Supervisor

ABSTRACT

Three experiments investigated methods to reduce forage waste during stored forage feeding using large round bale feeders (LRBF). In the first experiment, cone and sheeted LRBF reduced \((P < 0.05)\) fescue hay waste 54 and 29% respectively compared to standard open bottom LRBF but alfalfa haylage waste was not different \((P > 0.10)\) for feeders. Corn stover waste tended \((P = 0.12)\) to be less for cone (13.0%) LRBF compared to sheeted (31.7%) and open (38.5%) bottom LRBF in Experiment 2. In the third experiment, ammoniated corn stover waste was reduced \((P < 0.05)\) 64 and 46% for cone and sheeted LRBF compared to standard open bottom LRBF. Selective plant part consumption occurred with alfalfa haylage and corn stover but not with fescue hay. Corn stover ammoniation and LRBF did not affect component selective consumption. On average, waste was 6.1% for alfalfa haylage, 13.9% for fescue hay and 27.7% for corn stover suggesting forage quality, bale size, and forage moisture effect forage waste during feeding. Two additional studies investigated limiting access time (LAT) to eight hours per day as a method to reduce stored forage feeding waste. LAT reduced \((P < 0.05)\) forage disappearance 10% compared to \textit{ad libitum} standard open bottom LRBF access in both experiments. ADG was numerically reduced 9.1% with LAT compared to \textit{ad libitum} open bottom LRBF access in both experiments. Predicted forage waste in the second experiment was reduced 50.6 and 40.4% for \textit{ad libitum} cone LRBF access and LAT
respectively compared to *ad libitum* standard open bottom LRBF access. Cone and sheeted LRBF and LAT reduce stored forage waste during feeding with the latter reducing body weight gain. Future research should focus on the specific effects of bale to feeder size ratio, forage moisture content, LRBF stocking density, and forage maturity on stored forage waste during feeding.
CHAPTER 1

LITERATURE REVIEW

INTRODUCTION

Feed cost accounts for 63% total annual cow cost making feed the greatest profitability determinant for Midwest beef producers (Miller et al., 2001). Furthermore, Miller et al. (2001) identified the range from low to high cost production was greater than $1.00/cow/d suggesting improvements in forage utilization efficiency are possible and can increase profitability for cow-calf producers. Currently, large round bales are the predominant stored forage form used by beef producers, most likely due to lower baler cost and reduced waste in outdoor storage compared to large square bales (Cundiff and Marsh, 1996).

In a recent survey, 59% of producers selected “altering forage management” as their first strategy to reduce feed cost (Rutherford, 2013). Management strategies which increase stored forage utilization may be rapidly accepted and applied by US beef producers. Since 2003, hay production decreased 11% and price increased 77% as corn acres planted increased 20% (NASS, 2013). This evidence suggests corn stover is an available alternative forage for beef producers when hay stocks are low. Additionally, anhydrous ammonia treatment of low quality forage improves DM digestibility and DMI
Anhydrous ammonia treatment has potential to reduce low-quality forage refusal and waste.

Forage waste can occur during harvest, storage and feeding. Influence of storage method on forage waste has been well studied (Baxter et al., 1986; Belyea et al., 1985; Brasche and Russell, 1988; Lechtenberg et al., 1974). Grass hay waste during feeding has been studied to a lesser extent but can be influenced by access time and feeder design (Buskirk et al., 2003; Miller et al., 2007; Sexten, 2011). Forage type and feeder design interactions have not been evaluated. Thus the objectives of this thesis are to evaluate the effects of feeder design, access time, forage type, ammonia treatment, and ionophore supplementation on stored forage utilization.

LOSSES TO STANDING FORAGE DURING HARVEST

Initially, potential stored forage can be lost at harvest. Harvest efficiency is limited by technology available to beef producers but can be improved without improvement in harvest equipment. Efficiency improvements with current forage harvest systems can be made by altering harvesting moisture and harvesting equipment.

Sanderson et al. (1997) conducted a harvest efficiency study over three years where switchgrass hay was baled from 11 to 18% DM and observed baling loss ranged from 1 to 5% with greater losses associated with drier forage. They hypothesized drier forage promoted greater leaf shattering at harvest. In a similar study by Shinners et al. (2007), corn stover was flail chopped directly after grain harvest and baled immediately (55 to 70% DM) or dried (76 to 85% DM) then baled. Harvest efficiency was 50% for wet corn stover bales and 37% for dry corn stover bales. Harvest efficiency differences
between wet and dry corn stover were a result of improved baler pick up function with wet stover, forage degradation due to weather exposure during drying, and increased leaf shattering due to dry forage handling. Raking accounts for greatest DM losses associated with alfalfa production (Buckmaster, 1990). Buckmaster (1993) raked alfalfa ranging from 45 to 95% DM and reported increasing moisture content at raking reduced DM loss which ranged from 3.5 to 26.8%. Additionally, forage losses were 2.3% greater with a wheel rake compared to a bar rake. Buckmaster (1993) also noted greater CP, lower ADF and NDF in the forage DM lost during raking suggesting greater leaf proportions were lost during harvest.

Conclusions from the previous research indicate forage harvested at greater moisture content reduces DM losses during harvest and increase leaf retention while harvest equipment design can also influence harvest efficiency. However, Coblentz and Hoffman (2009) and Montgomery et al. (1986) baled alfalfa-orchard grass hay at varying moisture content and observed storage temperatures increased, DM digestibility decreased, and DM recovery decreased following storage with increasing round bale moisture. Thus harvest loss due to shattering should be balanced with the potential forage quality losses due to spontaneous heating. Coblentz and Hoffman (2009) observed DM recovery after large round bale storage (96.7%) was similar to square bales (95.5%) at 18% moisture but when forage was baled at 23% moisture, DM recovery following storage was reduced for large round bales (79.4%) compared to square bales (98.8%) suggesting square bales were more capable of exhausting moisture reducing DM losses due to microbial respiration.
Additional forage harvesting factors influencing forage utilization during storage and feeding include bale density, size, wrapping methods and harvest time of day. Lechtenberg et al. (1974) utilized several round balers to determine the effect of harvest machine and storage method on hay spoilage. Reducing bale density increased forage DM spoilage during outdoor storage due to greater weathering depth. Coblentz and Hoffman (2009) observed lower DM bale density in high (27 to 47% moisture) and intermediate (17 to 24% moisture) moisture bales compared to low moisture (9.3-17% moisture) bales. Coblentz and Hoffman (2009) baled forage into 1.5, 1.2 or 0.9 m diameter bales and observed heat dissipation occurred more rapidly in smaller diameter bales than larger diameter bales reducing the extent of spontaneous heating and forage quality losses. However during outdoor storage, greater surface area to volume ratio increases exposure to weather and increases DM and quality losses. During outdoor storage, larger bales can reduce waste if weathering is confined to the outside 5 to 10 cm of bale due to larger bales having less volume (% of bale) in the outer shell (Collins, 1997).

Fisher et al. (1999) mowed fescue hay in the morning (AM) or the afternoon (PM). Hay was then offered to sheep, goats and cattle side by side (AM or PM) in an effort to observe forage preference. PM fescue hay was preferred by all species over AM fescue hay due to lower NDF, ADF, and cellulose in PM hay compared to AM hay. Quality differences in AM and PM hay was explained by monosaccharide and disaccharide accumulation in the leaf during exposure to sunlight which dilutes forage fiber content.
Shinners et al. (2009b) related wrapping method to field hay loss and found baling forage losses were greater for twine tied bales (2.9% DM) compared to net wrapped bales (1.0% DM). Field loss differences were explained by losses during baler wrapping revolutions which were four for net wrap and 25 for twine wrap. Wrapping method also effected storage losses where bales stored directly on the ground yielded DM losses of 19.5, 11.3, 7.3, and 7.3% for sisal twine, plastic twine, to-edge net wrap and cover-edge net wrap respectively (Shinners, 2009b). The advantage of net wrap for large round bales stored outside compared to plastic twine was negligible when bales are not allowed soil contact as the net wrap accumulated moisture at the bottom of the bale (Harrigan, 1994). Harvest efficiency is a substantial loss in stored forage production suggesting harvest decisions can influence DM and quality losses during storage.

**STORED FORAGE LOSSES**

Storage is a major quantity and quality loss area in forage production and can be improved by reducing exposure to weather, soil and moisture. Various storage options are available to producers with a large range in infrastructure cost. The most common large round bale storage method for producers is outdoor storage in a row on the ground with no cover (Sexten, 2011).

*Stored Forage DM Losses*

Baxter et al. (1986) conducted two experiments to compare large round bale alfalfa-orchard grass hay storage method. In Experiment 1, hay was stored inside or outside with or without soil contact. DM loss was greatest for bales stored outside with soil contact (16.4%), intermediate for bales stored outside on tires (11.9%), and least for
hay stored inside (3.3%). In Experiment 2, hay was stored inside or outside on tires with or without cover. DM loss was greatest for bales outside uncovered (17.9%) while DM loss was not different for bales stored inside (8.0%) compared to bales stored outside and covered (5.0%). Cows had increased weight gain and greater milk production when fed barn stored hay compared to outside stored hay, but when the hay was covered and off the ground, milk production was not different from cows fed barn stored hay (Baxter et al., 1986). Forage stored off the ground and covered results in comparable DM loss to barn stored forage. These conclusions agree with results from Brasche and Russell (1988) where DM recovery following storage was greater for bales covered on tires than bales uncovered and stored with soil contact.

Belyea et al. (1985) stored large round alfalfa bales inside, outside uncovered, or outside covered in two or three high stacks. DM loss during storage was greatest for outside/uncovered hay (15.0%), intermediate for outside covered bales (5.8 and 6.6% for two high or three high respectively) and lowest for barn stored hay (2.5%). These results agreed with those of Baxter et al. (1986) where outdoor storage with no cover resulted in greater waste than covered and barn stored hay however soil contact was not evaluated. Storing forage with weather exposure decreased DM recovery by 57% while storing forage with soil contact decreased forage DM recovery by 27%. Belyea et al. (1985) also evaluated subsequent performance and feeding waste with dairy heifers. DM waste during feeding was greater for outside/uncovered hay (24.7%) compared to barn stored (12.4%), outside covered two-high (14.5%) and outside covered three-high (13.4%) which were not different. Heifer ADG (kg/d) was numerically lower for outside uncovered hay compared to barn and cover stored hay. DMI was not different due to
storage method, however intake was numerically greatest (2.35% BW) for barn stored hay and least (2.11% BW) for outside uncovered stored hay. Overall DM waste due to storage and feeding was greatest for outside uncovered (39.7%), intermediate for covered treatments (19.7% for three high and 20.4% for two high), and least for barn stored hay (14.8%).

Lechtenberg et al. (1974) observed mixed grass hay storage deterioration was 12.6, 14.5, and 22.3% for bales from three different harvest machines. When forage was offered to cows, additional hay needs were 22.6, 35.0, and 38.6% suggesting more forage waste occurred from bales with greater bale deterioration. Regardless of harvest machine, DM required was less when forage was fed in racks suggesting large round bale feeders use during feeding can reduce waste (Lechtenberg et al., 1974).

Shinners et al. (2007) harvested and stored corn stover as wet chopped and bagged, wet baled and wrapped, dry baled and stored inside and dry baled and stored outside, subsequent DM losses during 8 to 9 month storage were 5.4, 2.4, 3.3, and 18.1% respectively. Corn stover stored outside with soil contact resulted in DM losses of 10.0, 13.9, and 30.4% for bales wrapped with net wrap, plastic twine and sisal twine respectively. Dry baled stover stored in a barn has similar storage DM loss as wet stover chopped and bagged and wet stover baled and wrapped. Wrapping, bagging, and barn storing resulted in less waste compared to outdoor storage where net wrap yielded less waste due to lower total bale moisture (Shinners et al., 2007). DM recovery differences between plastic or sisal twine tied bales was explained by forage losses during handling with sisal tied bales due to sisal twine rotting during soil contact. In another study by Shinners et al. (2009a), alfalfa was baled at 25 and 50% moisture and preserved via
anaerobic fermentation. DM loss was not different due to moisture level (2.3% for 25% moisture vs. 3.5% for 50% moisture) and was similar for DM loss reported in dry, barn stored hay. Forage storage at varying moisture levels results in similar DM recovery if protected from weathering or ensiled properly, however storage waste is greater if soil contact and/or weather exposure is allowed or oxygen is present during ensiling. Storage method influences storage DM loss and contributes to feeding waste.

Stored Forage Quality Losses

Changes in forage chemical composition accompany DM losses during outdoor storage and can reduce hay nutritive value. Following mixed grass hay outdoor storage, Lechtenberg et al. (1974) observed DM digestibility was reduced approximately 8%. Digestibility reduction (56.5 to 36.8%) was measured in the weathered outside bale layers with no change in core DM digestibility. NDF, ADF, acid detergent lignin, and acid detergent insoluble nitrogen (ADIN) increased while in-vitro DM digestibility decreased between brome grass hay and alfalfa hay when stored outside and uncovered on the ground versus outside and covered on tires (Brasche and Russell, 1988). Nutrient losses during outdoor storage are caused by soluble nutrient exposure to moisture and microbial activity. Biological activity and subsequent respiratory losses increases at approximately 20% moisture, increasing losses in digestible nutrients (Collins, 1987; Montgomery et al., 1986).

Stored forage quality losses also occur due to spontaneous heating. Microbial heat production causes carbohydrate oxidation, mold growth, and increased fiber and ADIN concentrations (Coblentz et al., 1996). Coblentz and Hoffman (2009) harvested alfalfa-
orchardgrass hay at low (9.3 to 17.3%), intermediate (16.8 to 24.2%), and high moisture (26.7 to 46.6%) and concluded maximum internal bale temperature and days of internal temperature >30°C are both positively correlated with bale harvest moisture. Ash increased and digestibility linearly decreased with increasing maximum internal bale temperature. These results agree with research by Montgomery et al. (1986) who observed a peak internal bale temperature of 90°C when alfalfa-orchardgrass hay was harvested in large round bales at 23% moisture compared to 50°C for hay harvested at 18% moisture. Montgomery et al. (1986) also noted an increase in ADIN and a digestibility decrease in large round bales harvested at 23% moisture.

Limited data suggests contributing factors to DM and nutrient losses during outdoor storage include storage length, precipitation during storage, and bale shape. Shinners et al. (2009b) suggested increases in storage length and precipitation during storage increased DM loss due to greater internal bale moisture contributing to higher bacterial respiratory activity and soluble nutrient leaching. Belyea et al. (1985) described differences in precipitation across years as a contributing factor to differences in storage DM loss. Cundiff and Marsh (1996) found switchgrass hay stored in large square bales outside resulted in greater waste than large round bales under the same storage conditions due to increased surface area and absence of water shedding angles. Changes in nutritional quality and forage spoilage during storage can influence forage feeding refusals.
STORED FORAGE FEEDING

Multiple options exist for stored forage delivery to cattle. Options include: free-choice hay bales with or without feeders, restricted access hay bales, unrolling bales on the ground, mechanically processing forage to feed on the ground or in bunks, and windrow grazing. Volesky et al. (2002) required steer calves to consume windrow stored forage or feeder fed bales. Waste associated with windrow grazing was greater (29%) than bale feeding in a feeder (12.5%). Harvest cost reductions for windrowed forage offset wasted hay cost and lost nutrients making feeding windrowed forage a viable option in situations with cheap forage cost and high forage availability.

A three year study was conducted by Landblom et al. (2007) to determine stored forage delivery method cost. Forage fed during the first two years was alfalfa-brome grass-crested wheatgrass hay (58% OM digestibility) with oat hay (61.4% OM digestibility) fed in the third year. Round bale hay was fed on the ground via a bale processor, rolled out on the ground, or provided in a tapered-cone feeder. Forage required per cow was least for the tapered-cone feeder compared to rolling-out (5% more hay) or processed forage (15% more hay) in all three years. Increased fat deposition over the 12th rib for tapered-cone fed cows in years one and two suggest forage intake was greater for cows feeding from the tapered-cone feeder than processed or rolled out hay. Hay waste for processing or rolling out hay would be more dramatic if forage was offered at levels to promote similar intake. Additionally, Landblom et al. (2007) measured less forage waste with the tapered-cone feeder than with rolling out or processing alfalfa-brome grass-crested wheatgrass hay but not with oat hay. Increased taper-cone feeder
waste with oat hay was credited to decreased bale density. Feeding large round bale stored forage in a feeder results in less forage waste than alternative feeding methods.

Feeder Design

Large round bale feeders (LRBF) are the most commonly adopted stored forage feeding method for Oklahoma beef producers (Sexten, 2011). LRBF are popular as a hay saving method due to reduction in labor and equipment needs. Regardless of design, LRBF use reduces forage waste compared to no feeder when free choice hay is provided to cattle and horses due to a reduction in forage trampling (Lechtenberg et al., 1974; Martinson et al., 2012). Multiple LRBF designs are available to producers with a price range from $200 to $2,000.

In an effort to evaluate the effect of LRBF design on hay waste, forage intake, and feeding behavior, Buskirk et al. (2003) fed alfalfa and orchardgrass hay in four different feeders. Feeders styles used were cone, ring, trailer, and cradle feeders where the ring was sheeted on the bottom, the cone had top and bottom sheeting with a cone to suspend the bale, the trailer was elevated from the ground and had individual feeding spaces and the cradle feeder was elevated from the ground with no individual feeding spaces. Buskirk et al. (2003) observed different waste for all feeders. Waste as a percent of hay disappearance was 3.5, 6.1, 11.4 and 14.6% for cone, ring, trailer and cradle respectively. LRBF design had no effect on forage intake which ranged from 1.8 to 2.0 % of BW.

Buskirk et al. (2003) monitored cow feeding behavior and quantified agonistic interactions, entrance frequency (regular and irregular) and feeder occupancy rate. Agonistic interactions were defined as behavior between cows which displaced another
cow from the feeder. Regular entrances were defined as placement of the cows head within the defined feeding station. Irregular entrances were defined as entrance above the feeder’s defined feeding station. Occupancy was the amount of time cows spent at the feeder. Hay waste was correlated to entrances frequency and agonistic interactions. Buskirk et al. (2003) noticed feeder occupancy was lowest in the ring and cone feeders compared to the trailer and cradle feeder suggesting cows ate more efficiently once they entered the feeder. This was explained by reduced distractions because of round feeder shape or feeding comfort in a grazing-like position. Additionally, regular entrance frequency was numerically lower for ring and cone feeder compared to the cradle and trailer feeders supporting the observations made for feeder occupancy and suggesting waste is reduced with fewer entrances. Irregular entrance frequency was greater for cradle compared to cone, ring, and trailer which were not different. This was explained by the top neck bar confining cows to the defined feeding station indicating waste is related to irregular entrances. Agonistic interactions were three times greater for the cradle compared to the other three feeders which describes the benefits of defined feeding stations reducing cow interaction during feeding as dividing bars were not present in the cradle feeder to reduce cow interaction and waste during feeding. Dividing bars, defined feeding stations, round shape and a cone improve forage utilization by allowing cows to feed in a natural position without cow interaction.

Similar waste reductions for cone feeders was observed by Comerford et al. (1994) where forage was baled wet (40% DM) or allowed to dry. Both hay forms were fed in a cone or conventional ring feeder. Waste observed was 8.0% for the conventional ring feeder and 1.9% for the cone feeder. Cone feeders are effective at reducing hay
waste by providing a larger feeding space inside the feeder. Forage moisture did not affect hay feeding waste.

Sexten (2011) evaluated the effect of bale feeder design on hay waste with 56 crossbred cows. Ring feeders evaluated for this experiment were open bottom steel ring (OBSR), open bottom plastic ring (POLY), sheeted bottom (RING) and a modified cone feeder (MODC). MODC had bottom sheeting and tapered into the middle and back out at the top. RING feeder was the only feeder evaluated with individual feeding stations. Waste as a percent of bale DM weight was greatest for OBSR (20.7%) and POLY (21.5%), intermediate for RING (12.7%), and least for MODC (5.6%). These results agree with previous research were cone-type feeders reduced waste (Buskirk et al., 2003; Comerford, 1994). Bale feeder did not affect DMI which agrees with previous work (Buskirk et al., 2003). Waste reduction for RING compared to POLY and OBSR was due to presence of individual feeding spaces and bottom sheeting reducing agonistic interaction and retained more forage inside the bottom of the feeder.

Cone feeders result in 43 to 56% less waste than feeders with bottom sheeting, and bottom sheeting results in 39% less waste than feeders with open bottoms. Overall cone feeders can reduce waste by 73 to 76% when compared to conventional ring feeders. Feeding behavior research by Buskirk and others (2003) concluded bale feeder designs which reduce cow interaction and allow cows to feed inside the feeder in a natural grazing-like position reduce waste. Further research is needed to determine the effects of feeder to bale size ratio, feeder stocking rate, forage quality, and forage moisture level on hay waste.
Limiting Access Time

Limiting access time to stored forage has been proposed as a method to reduce cow wintering cost by reducing feeding waste and DM disappearance per cow (Cunningham et al., 2005; Miller et al., 2007). Cunningham et al. (2005) allowed 72 cow-calf pairs access for 4, 8, or 24 hours per day to high quality legume and grass mixed hay. A quadratic increase was observed for hay disappearance with increasing access time. Additionally, waste as a percent of disappearance was 9.8%, 13.0%, and 18.1% for 4, 8, and 24 hour access respectively however this difference was not significant due to large waste measure variability. Reducing access time also increased BW loss and linearly reduced body condition score suggesting limiting access time for lactating cows with high quality hay can result in undesirable weight loss.

Cunningham et al. (2005) also allowed 72 gestating cows stored forage access for 3, 5, or 7 hours per day with a fourth treatment of cows fed ground hay at 90% NRC requirements. A linear decrease in DM disappearance was observed with decreasing access time. In this study, no difference in hay waste as a percent of hay disappearance was observed for access time; however, ad libitum access was not evaluated for waste comparison to a conventional feeding system. Body weight gain increased linearly with increasing access time which agrees with the previous research but body weight gain was not different for 5 hours of access compared to cows fed at 90% NRC requirements.

Miller et al. (2007) provided 72 gestating cows 3, 6, 9 or 24 hours per day of stored forage access. Forage quality was considered high (17.6% CP, 45% NDF, 62.3% TDN). Hay disappearance increased linearly with increasing access time. Kilograms of
hay waste increased linearly with increasing access time however, when expressed as a percent of hay disappearance waste was not different due to access time although it was numerically greatest for *ad libitum* access compared to 6 hours of access. Cows with three access hours were aggressive towards feed which could have increased waste. A quadratic effect was observed as body weight gain increased at a decreasing rate with increasing access time suggesting cow performance and forage disappearance are optimized at nine access hours. In this experiment body weight gain and body condition changes were positive for all treatments suggesting when high quality forage is fed with limited access time to gestating cows, maintenance can be achieved. Miller et al. (2007) also provided 72 gestating cows 6, 9 or 24 hours of access to moderate quality forage (15.4% CP, 57.1% NDF, 61.2% TDN). Again, hay disappearance increased linearly with increasing access time. A quadratic effect for waste as a percent of disappearance was observed where waste was least at 9 hours and greater at 6 and 24 access hours. Increased waste at 6 hours might be explained by aggressive eating behavior. Body weight gain was not different due to access time while digestibility was numerically greatest at 6 hours of access and least for 24 hours.

Limiting access time can be used as a management tool to reduce stored forage DM disappearance. Limiting access time in lactating cows resulted in weight and body condition losses but maintenance was achieved and waste was reduced for gestating cows allowed nine forage access hours. Further research is needed to compare limiting access time to different feeder designs as limiting access time is more labor and facility intensive.
SORTING BEHAVIOR

Forage sorting is well documented for mechanically processed forage in high forage total mixed rations offered to dairy cattle. Historically, sorting is defined as a measurable change in quality components (NDF, ADF, CP, DM digestibility, and Ash) from forage offered to forage remaining in the orts. When given the opportunity, cows will selectively consume components with higher nutrient content and digestibility which is associated with the vegetative (leaf) and less mature forage fractions. Cows sort against stem and other highly lignified (low digestibility) plant material. Sorting high forage total mixed rations is decreased as forage moisture increases, forage particle size decreases and forage inclusion increases (DeVries et al., 2007; Leonardi and Armentano, 2003; Leonardi et al., 2005).

Forage sorting provided in bale or whole plant form has been studied to a much lesser extent and has rarely been related to feeding waste. Buskirk et al. (2003) observed lower OM, NDF, ADF and CP and higher acid detergent lignin concentration in waste compared to forage offered in large round bale feeders. Additionally, feeder design also influenced waste composition where the cone and ring feeders resulted in waste with less OM, NDF, and ADF than trailer and cradle feeders. Alfalfa and orchardgrass leaves were concentrated to a greater extent in the waste compared to the bale and leaf concentration was dependent on waste amount as ring and cone feeders resulted in less waste and had greater leaf concentration (Buskirk et al., 2003). These results disagree with those of Baxter et al. (1986) who observed ADF and lignin were higher and CP was lower in
refused alfalfa-orchardgrass hay compared to the bale. Greater ADF and lignin concentrations in refused forage indicated cows selectively consumed greater proportions of leaf and less mature stem. High quality forage can be sorted in total mixed rations and in ad libitum forage offerings in bale form. Although results are mixed, refused forage tends to have greater lignin concentrations suggesting cows are capable of sorting mature stem from vegetative plant fractions.

Maize and grain-sorghum stover provide sorting opportunities as the leaf and stem fractions are easily distinguished due to physiological plant maturity at harvest and large stem size and rigidity. Additionally, plant component quality is different as ADF and lignin are greater and CP and digestibility are lower in the stalk compared to the leaf (Methu et al., 2001; Weaver et al., 1978). Methu et al. (2001) offered non-processed corn stover to dairy cows at 3, 6 and 9% of body weight per day. DMI increased as DM offered increase. Additionally, as DM offered increased from 3 to 9% of body weight per day, leaf intake increased while stalk intake was not different. Cows selectively consumed leaf over stalk, evidenced by lower ADF and lignin concentration in consumed forage. Unfortunately, waste composition and amounts were not measured.

Osafo et al. (1997) offered chopped or whole sorghum stover at 2.5 or 5.0% of BW daily to sheep or cattle and found as forage offerings increased so did forage intake. Additionally, as offered stover increased from 2.5 to 5.0% of BW per day, leaf consumption increased in sheep and cattle regardless of forage processing method. Forage processing and amount offered interacted for cattle as stem consumption increased when chopped stover was offered at a greater amount but decreased when whole stover was offered at a greater amount. These results were not consistent by
species as sheep maintained the ability to selectively consume leaf regardless of forage processing. Sheep maintain the ability to sort processed forage due to greater lip prehension capability compared to tongue forage prehension in cattle (Luginbuhl, 1983). Processing stover can reduce forage sorting by cattle.

The effect of forage quality and plant composition on hay waste has not been well studied. Cattle are capable of sorting stover and alfalfa-orchardgrass hay. Sorting can be reduced by processing of forage into smaller particles which reduces the ability of cattle to physically sort the forage. Forage quality offered in bale or whole plant form can affect the amount of waste at feeding if cattle waste plant components which are less desirable to consume.

**ADDITIONAL TECHNOLOGIES TO IMPROVE FORAGE UTILIZATION**

Besides reducing forage waste, forage utilization by the animal can be improved through ionophore supplementation and forage ammoniation.

*Ammoniation of Low Quality Forage*

Treatment methods improving forage DM digestibility include mechanical processing, heat treatment, acid treatment, alkaline treatment and hydration (Hendriks and Zeeman, 2009). Alkaline forage treatment and mechanical processing are the most widely adopted methods in the livestock industry due to cost advantages and equipment availability. Only alkaline treatment in the form of anhydrous ammonia can be applied in whole bale form for broad application of forage treatment systems for multiple production settings.
Anhydrous ammonia treatment of low quality forage improves DM digestibility and DMI (Buettner et al., 1982; Paterson et al., 1981; Zorrilla-Rios et al., 1991). Improvements in DM digestibility occur due to increased hemicellulose, cellulose, and lignin digestibility (Birkelo et al., 1986; Hendriks and Zeeman, 2009). Solubility of hemicellulose, especially xylan and glucomannans (primary components of pectin), during alkaline treatment appears to be the primary mode of action for improved DM digestibility (Hendriks and Zeeman, 2009; Horton and Steacy, 1979; Paterson et al., 1981). Once hemicellulose is soluble, cellulose exposure allows hydrolysis to occur at a more rapid rate and to a greater extent (Hendriks and Zeeman, 2009).

Lalman et al. (2011) summarized wheat straw, corn stover, milo stover, prairie hay, fescue hay, orchardgrass hay, and switchgrass hay ammoniation, improvements in forage DMI were on average 20% with a 25% increase in DM digestibility suggesting increases in DMI are likely due to increases in DM digestibility. Improvements in DM digestibility from ammoniation vary depending on forage type (Horton and Steacy, 1979). Previous research indicates ammoniation benefits can occur at treatment rates as low as 2% (Paterson et al., 1981). High quality forage ammoniation and ammoniation at a rate greater than 4% are not recommended due to increased ammonia toxicity risk (Weiss et al., 1986). Feeding ammoniated forage to cows with nursing calves is also not recommended due to toxic compound secretion in milk (Weiss et al., 1986).

*Monensin Supplementation*

Monensin use in feedlot and growing cattle diets is widely adopted and improves feed efficiency and increases ADG (Duffield, ; Raun et al., 1976; Rouquette et al., 1980).
In a recent meta-analysis, Duffield et al. (2012) concluded monensin use in feedlot and growing cattle diets provides a 6% improvement in feed efficiency, 3% decrease in DMI, and a 2.5% increase in ADG. Monensin is used to a lesser extent in gestating and lactating beef cows as supplementation is seasonal or non-existent in most cow-calf operations. Monensin is also not approved for use in free choice mineral or tubs for grazing beef cows limiting its use in cow-calf operations. Limited research suggests monensin supplementation improves efficiency in cows on hay diets, however, the method this efficiency is achieved seems to vary considerably (Sprott et al., 1988).

Body weight gain response to ionophores is variable depending on production stage and forage quality (Sprott et al., 1988). Clanton et al. (1981) reported BWG for gestating beef cows on sorghum-sedan silage receiving 0, 50, 200 or 300 mg monensin•cow⁻¹•d⁻¹ during the pre-calving period was not different although DMI was reduced by design with increasing monensin level. Conversely, Turner et al. (1977) reported increased gain along with reduced forage intake in gestating beef cows receiving meadow hay and supplemented with monensin. Sexten (2011) fed monensin at 0 or 200 mg•cow⁻¹•d⁻¹ to gestating cows consuming low quality grass hay and observed increased ADG, improved BCS and no difference in DMI with monensin supplemented cows. Sexten (2011) also measured increased DM, OM, NDF, ADF, and CP digestibility for cows receiving supplemental monensin. Sprott et al. (1988) concluded in a review that body weight gain response was inconsistent with ionophore supplementation but DMI was often reduced improving efficiency. These conclusions agree with those of Muller et al. (2006) who summarized monensin reduces DMI and increases fluid milk production in forage fed dairy cows while milk component yields due to monensin supplementation.
tend to show inconsistent responses. Monensin improves forage use efficiency in
gestating beef cows, however the magnitude of this improvement and body weight gain
response are not well quantified.

SUMMARY

With recent increases in stored forage cost, beef producers need to develop and
implement a plan which optimizes forage utilization and capital input into their operation.
Stored forage DM and quality losses occur during harvest, storage, and feeding and can
significantly impact annual cow cost. Multiple options exist for improving stored forage
utilization; however these losses must be quantified before economic considerations of
forage waste can be made. Stored forage utilization can be improved by storing forage
without soil and weather exposure, feeding forage in improved feeders and implementing
access time restriction. Producers should also consider technologies such as ionophores
or ammoniation to improve forage use efficiency and animal performance. With any
operation, decisions should be based on sound economics to improve profitability. With
current pressure on stored forage stocks and no sign of short term improvement,
considerations to increase stored forage utilization must be made.
CHAPTER 2

EFFECT OF BALE FEEDER, FORAGE, AND MONENSIN ON HAY WASTE, DISAPPEARANCE, AND COW PERFORMANCE

ABSTRACT

Three bale feeders and two forage types were used to evaluate feeding waste with 48 spring-calving crossbred cows (124 ± 8 d in gestation) in a 3 X 2 factorial treatment arrangement within a Latin square design. Cows were stratified by age (4 ± 2.5 years), weight (517 ± 68.8 kg) and 12th rib ultrasound measured fat thickness (0.4 ± 0.16 cm) into six replicate pens with eight cows per pen. Supplemental treatments were 1 kg•hd⁻¹•d⁻¹ supplement with 182 g/909 kg monensin (Mon) or without monensin (Con). Bale feeders evaluated were open bottom with 17 slanted feeding stations (Open) (2.4 m diam., 1.2 m height), sheeted bottom with 15 slanted feeding stations and tapering sides (Taper) (2.1 m diam. top, 2.4 m diam. bottom, 1.2 m height, 0.5 m sheeting), and sheeted bottom and top with 16 straight feeding stations and chain cone (Cone) (2.3 m diam., 1.7
m height, 0.6 m bottom sheeting, 0.5 m top sheeting). Forages were alfalfa haylage (AH) (41% DM, 17% CP, 49% NDF) or fescue hay (FH) (92% DM, 7.5% CP, 66% NDF). We hypothesized cone and sheeting would reduce waste with FH, but not affect AH waste, in addition, monensin would improve efficiency. Total DMI was reduced ($P < 0.05$) for Mon (2.2% BW) compared to Con (2.3% BW) while ADG, final BW, G:F and final 12th rib fat depth did not differ ($P > 0.10$). A forage and feeder interaction ($P < 0.05$) was observed for percent bale wasted where FH Open was greatest ($P < 0.05$) (19.2%), FH Taper was intermediate ($P < 0.05$) (13.6%) but greater than ($P < 0.05$) FH Cone (8.9%). However, FH Cone was not different ($P > 0.10$) from AH Open (7.0%), or AH Cone (6.5%) but was greater than AH Taper (4.9%). 24, 48, 72 h and total AH waste was not different ($P > 0.10$) due to feeder. 24 and 48 h FH waste was greater ($P < 0.05$) for Open and Taper compared to Cone. However, 72 and 96 h FH waste was greater ($P = 0.06$) for Open and Cone compared to Taper. Cone feeder and bottom sheeting were effective at reducing FH waste while monensin reduced forage intake with no impact on cow performance.
INTRODUCTION

Feed cost accounts for 63% of total annual cow cost and is the greatest variable influencing Midwest producers profitability (Miller et al., 2001). In the last decade, hay production decreased 11% while hay price increased 77% (NASS, 2013). More efficient harvested feed use can be achieved by reducing waste in large round bale storage and feeding systems (Baxter et al., 1986; Belyea et al., 1985; Buskirk et al., 2003; Landblom et al., 2007; Lechtenberg et al., 1974).

Large round bale feeders are the most adopted stored forage feeding method for Oklahoma beef producers (Sexten, 2011). Bale feeder design impacts hay waste by altering agonistic interactions, entrance frequency (regular and irregular) and feeder occupancy (Buskirk et al., 2003). Ring feeders allow cattle to eat in a natural position preventing hay loss from infrequent entrances (Buskirk et al., 2003). Cone-type feeders also reduce hay waste by providing a larger feeding area inside the feeder (Buskirk et al., 2003; Comerford, 1994). The effect of feeder design on different forage type waste is unexplored. The experimental objective was to quantify hay waste using three bale feeder designs and two forage types, while evaluating monensin’s effect on forage intake and performance of gestating beef cows. We hypothesize fescue hay will result in greater waste than alfalfa haylage. Additionally, cone-type feeders and sheeting will reduce waste with fescue hay but not alfalfa haylage while supplemental monensin will improve gain efficiency.
MATERIALS AND METHODS

Cows, Supplements, and Facilities

Forty-eight spring calving Simmental and Angus crossbred cows 124 ± 8 d in gestation were used in a 3 X 2 factorial treatment arrangement within a 6 X 6 Latin square design. Three bale feeder designs and two forage types were used to evaluate the effect of bale feeder and forage type on hay waste, DMI, and cow performance. Cows were stratified by age (4 ± 2.5 years), weight (517 ± 68.8 kg), body condition score (5.5 ± 0.42 units) and ultrasound measured 12th rib fat thickness (0.4 ± 0.16 cm) into six replicates with eight cows per replicate. Each replicate was randomly assigned to one of six, 16.6 X 7.3 m concrete pens with 4.5 m bunk space. Facilities were open to the south and hay sampling pad was 8.8 X 7.3 m with the remainder of the pen covered by roof and bedded with sawdust. Supplements were randomly assigned to pen (three pens/supplement). Supplement treatments were 1 kg•cow⁻¹•d⁻¹ supplement with 182 g/909 kg monensin (Mon) (Rumensin90; Elanco Animal Health; Greenfield, IN) or without monensin (Con) (Table 2.1). Replicates remained in pen with bale feeder and forage type rotated upon completion of each sample period.
Feeders

Three bale feeder designs were open, taper, and cone (Figure 2.1). **Open** had no sheeting and measured 2.4 m diam. and 1.2 m in height. **Taper** had 0.5 m of straight bottom sheeting, and measured 2.4 m bottom diam., 2.1 m top diam., and 1.2 m in height. **Cone** was 2.3 m in diameter, 1.7 m in height, and had 0.6 m bottom sheeting, 0.5 m top sheeting and a 16 chain cone spaced at 41 cm. Feeding spaces for open (n = 17) were 41 cm wide and 65 cm tall and bars were oriented at 73 degree angle. Cone dividers were oriented at 90 degree with a feeding space (n = 16) 41 cm wide and 69 cm tall. Taper dividing bars were oriented at 74 degree angle with a 46 cm wide and 66 cm tall feeding space (n = 15).

Forage

Two forage types were used to determine the interaction of bale feeder and forage. Alfalfa haylage (**AH**) was harvested May 18th 2012 (1st cutting) and ensiled as plastic wrapped bales. Fescue hay (**FH**) was harvested June 19th 2012 and barn stored until experiment initiation. AH bales were 1.5 m in height and 1.1 m in diam. with a mean dry matter bale weight of 364 ± 34 kg. FH bales were 1.5 m in height and 1.5 m in diam. with a mean dry matter bale weight of 546 ± 45 kg. Bale DM and forage quality was determined from three core samples (Hayprobe, Hart Machine Co., Madras, OR) collected from each bale (Table 2.2). Bales were orientation horizontally in the feeder and removed from storage no greater than five days prior to feeding.
**Waste Collection**

During FH sampling period, one bale was provided for acclimation to feeder design for 96 h. At 96 h, orts and debris were removed from feeding pad and a new bale was introduced. Waste was collected at 24, 48, 72, and 96 h following new bale introduction. At 96 h, orts were removed from feeder, weighed, and sampled. After orts were removed, a new bale was introduced for replication. Waste was considered forage outside of the bale ring and orts were forage remaining in the feeder. Waste was divided into contaminated and clean forage subgroups. Clean forage was classified as manure and urine free forage. Contaminated forage was contaminated with urine or manure which could not be sorted out during sampling. Manure was sorted from sample but some contamination was unavoidable. Waste subgroups were then weighed and subsampled for DM, CP, NDF, ADF, and ash determination. Total waste and quality estimates were composited as a weighted mean of contaminated and clean forage for calculations and statistical analysis.

Waste collection methods for AH were similar to FH however two bales were allowed for acclimation and two bales were provided for collection. Two AH bales were provided for acclimation to maintain a 12 d period. Waste collection and samples were taken at 24, 48, and 72 h due to less DM per bale. Experimental duration was 72 d with 24 h fasted body weight, BCS, and 12th rib fat depth taken at the beginning and end of trial. Fasted BCS were assigned on a one to nine scale (1 = extremely thin, 9 = obese) by two experienced evaluators.
Sample Analysis

Forage samples were immediately dried at 55º C for 72 h, ground through a 5 mm screen in a Wiley Mill (Model 4, Thomas Scientific; Sweedesboro, NJ), subsampled and ground through a 1 mm screen using a 1093 Cyclotech Mill (Tecator; Eden Prairie, MN 55344). Wet chemistry methods were used for DM (dried 12 h at 100º C), CP (% N X 6.25; FP-428 LECO Corporation; St. Joseph, MI 49085), NDF and ADF (Ankom Tech Corp; Fairport, NY) and ash (combusted 8 h in a muffle furnace at 500º C) for approximately half the samples to generate prediction equations. Samples were then placed in glass vial and analyzed using a FOSS XDS monochromator XM-1000 fitted with a XDS rapid content analyzer XM-1100 (FOSS NIRSystems Inc.; Laurel, MD). Resulting $R^2$ for DM, CP, NDF, ADF and ash predictions were 0.88, 0.99, 0.90, 0.89, and 0.85 respectively.

Statistical Analysis

Separate analyses were conducted to evaluate treatment means and repeated measures. Analysis one of treatment means was performed as a 6 X 6 Latin square. Treatments were arranged as a 3 X 2 factorial (feeder = 3, forage = 2). Columns represented six pens and rows represented six periods. Pen was the experimental unit and bale within period was considered a pseudo-replicate. Analysis two parameters taken over time (24, 48, and 72) were analyzed as a 6 X 6 Latin square with repeated measurement. The main plot contained the effect of column, row, and treatment combinations (forage, feeder, forage*feeder). The subplot contained the effects of time and all interactions with forage and feeder. 96 h measures were analyzed without the
effect of forage. Analysis three was similar to analysis two except measures (CP, ADF, NDF, and ash) were analyzed by component (bale, waste, and orts) instead of over time. All differences were determined using Fishers Least Significant Difference from the LSMEANS statement in PROC MIXED of SAS 9.3 (SAS Inst. Inc.; Cary, NC). Treatments were considered to be different at $\alpha \leq 0.05$.

Supplemental monensin was assumed to have no impact on hay waste (Sexten, 2010). Cow performance was analyzed using the GLM procedure of SAS 9.3 (SAS Inst. Inc.; Cary, NC) with pen as the experimental unit.

RESULTS AND DISCUSSION

Feeder and Forage

Results for waste, orts and intake are shown in Table 2.3. A forage by feeder interaction ($P < 0.01$) was observed for percent bale wasted where FH Open (19.2%) was greatest ($P = 0.02$), FH Taper was intermediate (13.6%) but greater than ($P < 0.01$) FH Cone (8.9%). However, FH Cone was not different ($P > 0.15$) from AH Open (7.0%), or AH Cone (6.5%) but was greater than ($P = 0.03$) AH Taper (4.9%). These results agree with previous research where cone-type feeders reduced grass hay waste (Buskirk et al., 2003; Comerford, 1994; Sexten, 2011; Sparks, 2013). In the present study, cone feeder
resulted in 35% less waste than taper feeder which is less than results presented by Sparks et al. (2013) and Buskirk et al. (2003) where cone feeder resulted in 43 to 50% less mixed grass hay waste than sheeted feeder. The flexible cone (chain) in the current study compared to solid (steel bar) cone in previous studies may increase waste in cone feeders. Additionally, bottom sheeting on taper feeder resulted in 30% less waste compared to open which is similar to 39% reported by Sexten (2011). Reductions in AH waste compared to FH waste were credited to differences in bale size, density, moisture level, and forage quality. Previous research suggests moisture level does not influence grass hay waste. Comerford et al. (1994) observed no difference in feeding waste of dry bales (90% DM) compared to silage bales (40% DM) harvested from the same forage lot.

The effect of bale size on hay waste has not been studied. However, Schultheis and Hires (1982) reported that pusher headgates requiring cattle to reach for forage reduced waste. In the present study AH bales were smaller than FH bales and feeder size was constant, suggesting cows had to reach further to consume AH, potentially reducing waste. The effect of forage quality on hay waste has not been reported. Average waste for AH was 6% and was comparable to waste observed on high concentrate diets suggesting high quality forage palatability could be similar to grain-based diets. Orts were inversely related to waste where there was no difference ($P > 0.20$) for FH Open (46 kg), AH cone (26 kg), AH taper (37 kg) or AH open (34 kg). Orts tended ($P = 0.10$) to be greatest in FH Cone (102 kg), FH Taper (76 kg) was intermediate and greater than ($P = 0.06$) FH Open.

Waste by day is presented in Figure 2.2 and 2.3. A feeder, forage and day interaction ($P < 0.01$) was observed for waste by day where no difference ($P > 0.15$) was
observed for percent AH waste due to day or feeder with the exception of 48 h AH cone waste which tended ($P = 0.10$) to be greater than 48 h AH taper waste. FH cone resulted in less waste ($P < 0.01$) at 24 and 48 h compared to FH open and FH taper which were not different ($P = 0.39$). Additionally, FH taper resulted in less waste ($P < 0.07$) at 72 and 96 h compared to FH cone and FH open which were not different ($P > 0.25$). Differences in FH waste at 24 and 48 h explain the waste reducing feature of the cone feeders.

Suspending the bale in a cone provides greater feeding space inside the feeder, thus cows were able to eat in a grazing-like position inside the feeder which reduces hay waste (Buskirk et al., 2003). Providing feed at ground level (grazing-like position) reduces forage waste by reducing feed tossing behavior compared to providing feed in an elevated bunk (Albright, 1993).

Feeding space can be defined as the area allowed for feeding inside the feeder and is measured as the distance between the newly introduced bale and the feeder. Feeding space inside open and taper feeders was approximately 0.45 m and 0.38 m respectively at new FH bale introduction while cone feeder feeding space was the feeder diameter as the bale was suspended in the chain. Greater waste at 24 and 48 h for FH taper and FH open suggest feeding space was inadequate for cows to feed naturally inside the feeder, increasing entrance frequency and thus increasing waste. The cone feeder resulted in increased FH waste at 72 and 96 h as the bale was no longer suspended by the cone and the protective sheeting filled with forage. Taper resulted in less waste than open at 72 and 96 h due to sheeting retaining more forage inside the feeder, once space was provided for cows to comfortably feed inside the feeder. Sheetimg at the bottom of the feeder reduces waste when forage remaining in the feeder is loose later in the feeding period.
Sorting

Sorting was not different \((P = 0.46)\) due to feeder, however, there was a forage by component interaction \((P < 0.01)\) (Table 2.4). Sorting was evident with AH as there was a reduction in CP and an increase in ADF for waste and orts compared to initial bale. There was no evidence of selective leaf consumption for FH as CP was not different for initial bale, waste, or orts. However, a reduction in FH waste ADF was observed suggesting FH waste contained a greater leaf concentration. These results agree with those of Buskirk et al. (2003) where OM, NDF, and ADF were lower in the waste, suggesting leaf was a greater proportion of dry alfalfa and orchardgrass waste. Greater leaf waste proportions is a product of leaf shattering during feeding which is less likely to occur with wet forage. Our results disagree with Leonardi et al. (2005) who saw a decrease in sorting with addition of water to a 40% forage diet. DeVries et al. (2007) reported sorting against NDF but to a greater extent in 50% forage than a 62% forage diet. Determining whether increased AH sorting observed in the current experiment is due to no additional processing or disagrees with previous research because it was offered \textit{ad libitum} in bale form and not in a total mixed ration is difficult. Increased sorting in AH compared to FH could be explained by less orts for AH (32.2 kg) compared to FH (74.7 kg) forcing cows to sort the remaining forage. Differences in sorting could also be a product of easier distinction of leaf from stem in a legume compared to a cool season grass.

Monensin

BW gain and forage intake data are summarized in Table 2.5. Total DMI was reduced \((P < 0.05)\) for Mon (2.2% BW) compared to Con (2.3% BW) which agrees with
a review by Sprott et al. (1988). ADG, final BW and final 12th rib fat depth were not
different \((P > 0.10)\) which agrees with research presented by Clanton et al. (1981) who
reported BWG for gestating beef cows on sorghum-sudan silage receiving 0, 50, 200 or
300 mg\(\cdot\)cow\(^{-1}\)\(\cdot\)d\(^{-1}\) during the pre-calving period was not different. Conversely, Turner et
al. (1977) reported increased gain along with reduced forage intake in gestating beef
cows receiving meadow hay. BWG response to ionophores on forage diets has been
documented to vary based on stage of production and forage quality (Sprott et al., 1988).
In the current study, calculated G:F was not different \((P = 0.96)\) for cows receiving 0 or
200 mg\(\cdot\)cow\(^{-1}\)\(\cdot\)d\(^{-1}\) which might be explained by abrupt changes from AH to FH forages
for the project duration.

**IMPLICATIONS**

As hypothesized, feeder influenced FH waste and had no impact on AH waste.
Open resulted in the greatest amount of FH waste, taper was intermediate, and cone
resulted in the least amount of FH waste. AH waste was not different due to feeder and
ranged from 5 to 7\%. FH waste ranged from 9 to 19\% suggesting feeder choice is an
important economic decision. Cone and sheeted feeders reduced fescue hay waste 54 and
30\%, respectively. Stored forage use can be improved in traditional hay feeding systems
with implementation of cone and sheeted feeders. Monensin can be used to reduce DMI in a forage rotation feeding system although feed efficiency may not be improved.

Further research is needed to determine effects of moisture level, forage quality, bale to feeder size and feeder stocking density on stored forage utilization.
<table>
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<tr>
<th>Item, % DM</th>
<th>Supplement</th>
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<tbody>
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<tr>
<td>Dried distillers grains + solubles</td>
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<tr>
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<td>Ground corn</td>
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</tr>
<tr>
<td>Monensin, g/909 kg</td>
<td>0</td>
</tr>
<tr>
<td>DM</td>
<td>89.3</td>
</tr>
<tr>
<td>CP</td>
<td>19.0</td>
</tr>
<tr>
<td>NDF</td>
<td>26.0</td>
</tr>
<tr>
<td>ADF</td>
<td>7.5</td>
</tr>
<tr>
<td>Ash</td>
<td>11.5</td>
</tr>
</tbody>
</table>

\(^a\) Mineral Premix= 19.8% NaCl, 37.0% CaCO\(_3\), 10.5% MgO, 11.4% trace mineral premix (3.0% Zn, 2.5% Fe, 2.0% Mn, 1.0% Cu, 100 ppm Co, 500 ppm I, 100 ppm Se), 12.7% vitamin premix (8,800,000 IU/kg vitamin A, 1,760,000 IU/kg vitamin D, 1,100 IU/kg vitamin E) and 8.7% vitamin E premix (4,400 IU/kg)
Table 2.2. NIR determined DM forage nutrient composition and bale size

<table>
<thead>
<tr>
<th>Item, %</th>
<th>Fescue</th>
<th>Alfalfa</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td>92.0</td>
<td>41.0</td>
<td>0.88</td>
</tr>
<tr>
<td>CP</td>
<td>7.5</td>
<td>17.0</td>
<td>0.99</td>
</tr>
<tr>
<td>NDF</td>
<td>66.6</td>
<td>49.4</td>
<td>0.90</td>
</tr>
<tr>
<td>ADF</td>
<td>36.4</td>
<td>34.4</td>
<td>0.89</td>
</tr>
<tr>
<td>Ash</td>
<td>10.5</td>
<td>9.1</td>
<td>0.85</td>
</tr>
<tr>
<td>Bale diam., m</td>
<td>1.5</td>
<td>1.1</td>
<td>.</td>
</tr>
<tr>
<td>Bale width, m</td>
<td>1.5</td>
<td>1.5</td>
<td>.</td>
</tr>
<tr>
<td>Bale wt., kg</td>
<td>546</td>
<td>364</td>
<td>.</td>
</tr>
</tbody>
</table>
Table 2.3. Effect of forage type and bale feeder on hay waste, orts, and disappearance (DM basis)

<table>
<thead>
<tr>
<th>Item</th>
<th>Forage and Feeder Treatment</th>
<th>P-value&lt;sup&gt;3&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alfalfa&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Fescue</td>
</tr>
<tr>
<td></td>
<td>Cone&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Taper</td>
</tr>
<tr>
<td>Bale wt., kg</td>
<td>366</td>
<td>353</td>
</tr>
<tr>
<td>Orts, kg</td>
<td>26.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>37.0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Waste kg</td>
<td>23.4&lt;sup&gt;d&lt;/sup&gt;</td>
<td>17.8&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>% Bale&lt;sup&gt;5&lt;/sup&gt;</td>
<td>6.5&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>4.9&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>% DMI&lt;sup&gt;6&lt;/sup&gt;</td>
<td>7.5&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>5.9&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>DMI, % BW&lt;sup&gt;7&lt;/sup&gt;</td>
<td>2.32</td>
<td>2.18</td>
</tr>
</tbody>
</table>

<sup>1</sup> Alfalfa = alfalfa haylage, Fescue = mature fescue hay

<sup>2</sup> Feeder: Cone = chain cone with top and bottom sheeting, Taper = straight bottom sheeting and tapering to top, Open = no sheeting

<sup>3</sup> Observed significance levels for forage, feeder and interaction of forage and feeder

<sup>4</sup> Standard error of least squared means

<sup>5</sup> Forage waste expressed as a percentage of DM bale weight

<sup>6</sup> Forage waste expressed as a percentage of total hay calculated DMI

<sup>7</sup> Average daily forage disappearance expressed as a percent of calculated midpoint body weight
Table 2.4. Effect of forage on CP, ADF and ash in bale, waste, and orts

<table>
<thead>
<tr>
<th>Item, % DM</th>
<th>Alfalfa</th>
<th>Fescue</th>
<th>SEM</th>
<th>Forage</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bale&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Waste</td>
<td>Orts</td>
<td>Bale&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Waste</td>
</tr>
<tr>
<td>CP</td>
<td>17.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>14.7&lt;sup&gt;c&lt;/sup&gt;</td>
<td>7.2&lt;sup&gt;d&lt;/sup&gt;</td>
<td>7.4&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>ADF</td>
<td>34.4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>37.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>40.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>36.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>33.7&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Ash</td>
<td>9.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>10.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8.9&lt;sup&gt;c&lt;/sup&gt;</td>
<td>10.5&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>10.9&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

1 Alfalfa = alfalfa haylage, Fescue = mature fescue hay
2 Observed significance levels for forage and component and their interactions
3 Component: Bale=bale core samples, Waste= waste grab samples composited by mass, Orts=orts grab samples
4 Largest standard error of least squared means
Table 2.5. Effect of monensin on cow performance and DMI

<table>
<thead>
<tr>
<th>Item</th>
<th>Supplement¹</th>
<th>Control</th>
<th>Monensin</th>
<th>SEM²</th>
<th>P-value³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial BW, kg</td>
<td></td>
<td>516.2</td>
<td>519.2</td>
<td>2.74</td>
<td>0.33</td>
</tr>
<tr>
<td>Final BW, kg</td>
<td></td>
<td>620.9</td>
<td>620.2</td>
<td>6.71</td>
<td>0.92</td>
</tr>
<tr>
<td>ADG, kg/d</td>
<td></td>
<td>1.41</td>
<td>1.36</td>
<td>0.09</td>
<td>0.60</td>
</tr>
<tr>
<td>12th rib fat depth⁴, cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td></td>
<td>0.40</td>
<td>0.40</td>
<td>0.007</td>
<td>0.64</td>
</tr>
<tr>
<td>Final</td>
<td></td>
<td>0.73</td>
<td>0.63</td>
<td>0.069</td>
<td>0.24</td>
</tr>
<tr>
<td>DMI⁵, % BW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fescue</td>
<td></td>
<td>2.29</td>
<td>2.16</td>
<td>0.09</td>
<td>0.22</td>
</tr>
<tr>
<td>Alfalfa</td>
<td></td>
<td>2.33</td>
<td>2.27</td>
<td>0.11</td>
<td>0.64</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>2.31</td>
<td>2.22</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Total G:F</td>
<td></td>
<td>0.102</td>
<td>0.102</td>
<td>0.007</td>
<td>0.96</td>
</tr>
</tbody>
</table>

¹ Control = 0 mg•head⁻¹•d⁻¹ monensin, Monensin = 200 mg•head⁻¹•d⁻¹ monensin
² Largest standard error of least squared means
³ Observed significance level for supplement
⁴ Ultrasound measured 12th rib fat thickness
⁵ Calculated DMI as a percent of calculated midpoint BW
Figure 2.1. Round bale feeder designs: (a) open, (b) taper, and (c) cone.
Figure 2.2. Alfalfa waste by 24 h period expressed as a percent of bale weight
Figure 2.3. Fescue waste by 24 h period expressed as a percent of bale weight
CHAPTER 3

COMPARISON OF FORAGE DISAPPEARANCE AND CALF PERFORMANCE FOR ACCESS TIME RESTRICTION AND FEEDER DESIGN

ABSTRACT

Two experiments were conducted to evaluate the effects of bale feeder design and restricting access time (RAT) on forage disappearance and calf performance. We hypothesize cone feeder and RAT would reduce forage disappearance with the latter reducing calf performance. In Experiment 1, Red Angus crossbred heifers were randomly assigned to RAT (8H) or ad libitum (24H) access to hay in year 1 (YR1) (n = 52) and year 2 (YR2) (n = 64). Three pens per treatment were used in YR1 with a 107 d development period while four pens per treatment were used for a 93 d period in YR2. Forage was offered in alternate bale feeders which were moved prior to new bale introduction. Heifers were fed dried distillers grains with solubles based supplement at 2.0 kg DM•hd⁻¹•d⁻¹. In Experiment 2, 108 Red Angus crossbred calves were stratified by
sex, body weight (275 ± 22.3 kg), and sire type (AI or natural service) into nine replicates with 12 calves per replicate (six steers and six heifers). Replicates were randomly assigned to one of three treatments: 8 h RAT per day (TIME), *ad libitum* access to a standard bale feeder (OPEN), and *ad libitum* access to cone feeder (CONE) resulting in three replicates per treatment. Large round bales were offered in a single feeder whenever visually appraised forage remaining was estimated to limit intake. Calves were offered dried distillers grains with solubles, cracked corn, and ground sorghum grain supplement with lasalocid at 2.8 kg• calf⁻¹• d⁻¹. In Experiment 1, access time and year tended (*P* = 0.09) to interact for development ADG where YR1 24H had greater (*P* < 0.05) ADG than 8H while in YR2 no differences (*P* > 0.10) were observed due to access time. Total and daily hay disappearance was reduced (*P* < 0.01) by 10.0% due to 8H. In Experiment 2 ADG was different (*P* = 0.05) due to treatment where CONE resulted in greater (*P* = 0.02) ADG (1.11 kg/d) than TIME (1.00 kg/d) and tended (*P* = 0.10) to result in greater gains than OPEN (1.04 kg/d). ADG was not different (*P* = 0.24) for OPEN and TIME. Forage disappearance as a percent of body weight was less (*P* < 0.01) for TIME (1.28% BW) compared to OPEN (1.47% BW) and CONE (1.48% BW) which were not different (*P* > 0.50). RAT can reduce calf forage DMI while cone type feeder use and RAT can reduce growing calf forage usage.
INTRODUCTION

Feed cost accounts for 63% of total annual cow cost and is the greatest variable influencing Midwest producers profitability (Miller et al., 2001). In the last decade, hay production decreased 11% while hay price increased 77% (NASS, 2013). More efficient harvested forage use can be achieved by reducing waste in large round bale storage and feeding systems (Baxter et al., 1986; Belyea et al., 1985; Brasche and Russell, 1988; Buskirk et al., 2003; Landblom et al., 2007; Lechtenberg et al., 1974).

Large round bale feeders are the most adopted stored forage feeding method for Oklahoma beef producers (Sexten, 2011). Generally, cows are provided *ad libitum* access to large round bales in feeders. Unrestricted access forage waste can be reduced by using sheeted and cone-type feeders (Buskirk et al., 2003; Comerford, 1994; Sexten, 2011). Additionally, restricting access time (RAT) to large round bale feeders can reduce high-quality forage waste (Cunningham et al., 2005; Miller et al., 2007). However, RAT to high-quality forage resulted in variable performance responses where lactating cows lost more weight as access time was reduced but gestating cows maintained acceptable weight when high-quality forage access was restricted due to lower energy requirements (Cunningham et al., 2005; Miller et al., 2007). RAT has the opportunity to reduce forage intake with gestating cows and developing heifers as maximal energy intake is not required to meet production goals. Production goals are generally described as
maintenance for gestating cows and low ADG for heifers developed to target weight at spring breeding. Optimal RAT for waste reduction and gestating cow maintenance occurs between six and nine forage access hours per day (Miller et al., 2007).

The experimental objectives were to quantify growing calf performance and forage disappearance for *ad libitum* access to different feeder designs or RAT to large round bales. We hypothesized eight access hours will reduce forage disappearance and growing calf performance while cone feeder will result in less forage disappearance but similar gains to standard feeder.

**MATERIALS AND METHODS**

*Experiment 1*

Red-Angus crossbred heifers were used to evaluate two treatments: *ad libitum* access to large round bales (24HR) or eight hours of large round bale access (8HR) over a two years period. In yr. 1, 52 heifers were stratified by body weight (327 ± 26 kg), birth date, and sire group (AI or natural service) into six replicates with eight or nine heifers per replicate (three replicates per treatment) and fed for 107 d. In yr. 2, 64 heifers were stratified by body weight (315 ± 24 kg), birth date, and sire group into eight replicates with eight heifers per replicate (four replicates per treatment) and fed for 93 d. Replicates
were randomly assigned to forage access treatments. Two day full body weights were taken at experiment initiation and termination with interim weights collected every 28 d. A common diet with *ad libitum* forage access was fed five days prior to 2 d final body weight collection. Upon experiment conclusion, heifers were palpated for pelvic area and reproductive tract score evaluation by a licensed veterinarian.

Heifers were housed in dry lot pens containing two large round bale feeders with 122 m$^2$ per heifer. Bale feeders measured 2.43 m in diam., 1.1 m in height, and had 18 slanted bar feeding stations with no bottom sheeting (Figure 3.1). One large round hay bale was placed in a ring feeder within each pen. Once visually appraised bale consumption was greater than 85%, a new bale was offered in the alternate bale ring. Feeders were moved prior to new bale introduction and any forage remaining in the feeder was considered waste and not measured. 8HR access was restricted using electric polywire. Weight and three core samples were taken from each bale to determine DM offered and forage quality. Hay in yr. 1 (89.3% DM, 10.4% CP, 60.3% NDF, 39.2% ADF) was from two similar lots while yr. 2 (88.0% DM, 10.4% CP, 60.6% NDF, 41.3% ADF) forage was from three similar fescue hay lot. Upon experiment completion, forage remaining in the feeder was weighed and sampled for DM determination to calculate pen forage disappearance. All forage and feed samples were analyzed for nutrients using wet chemistry methods.

Heifers were offered dried distillers grains with solubles based supplements in both years (Table 3.1). Heifers were fed 2.0 kg DM•heifer$^{-1}$•d$^{-1}$ in yr. 1 and 2.1 kg DM•heifer$^{-1}$•d$^{-1}$ in yr. 2 corresponding to 0.61 and 0.64% initial body weight for yr. 1 and 2
respectively. Feed offered was divided equally into morning and evening feedings just prior to and following limited access to large round bales.

Data were analyzed as a randomized complete block design with the fixed effects of year and access times with pen as the experimental unit. All differences were determined using Fishers Least Significant Difference from the LSMEANS statement in PROC MIXED of SAS 9.3 (SAS Inst. Inc.; Cary, NC). Treatments were considered to be different at \( \alpha \leq 0.05 \).

**Experiment 2**

One-hundred and eight, Red Angus crossbred calves were stratified by sex, body weight (275 ± 22.3 kg), and sire type (AI or natural service) into nine replicates with 12 calves per replicate (six steers and six heifers). Replicates were randomly assigned to one of three treatments: hay access time limited to 8 h per day (TIME), *ad libitum* access to a standard bale feeder (OPEN), and *ad libitum* access to cone feeder (CONE) resulting in three replicates per treatment. Open feeder was used for OPEN and TIME treatments and measured 2.43 m in diam., 1.1 m in height, and had 18 slanted bar feeding stations with no bottom sheeting (Figure 3.1). Feeder used for CONE treatment was 2.3 m in diameter, 1.7 m in height, and had 0.6 m bottom sheeting, 0.5 m top sheeting and a 16 chain cone spaced at 41 cm with 16 straight feeding stations (Figure 3.2).

Cattle were weaned 20 d prior to experiment initiation, vaccinated with Bovi-Shield Gold 5 (Zoetis Animal Health; Madison, NJ 07940) and Covexin 8 (Merck Animal Health; Summit, NJ 07901), and de-wormed with Cydectin Pour-on (Boehringer Ingelheim Animal Health; Ridgefield, CT 06877). Steers were implanted at experiment initiation with Revalor IS (Merck Animal Health; Summit, NJ 07901) while heifers were
not implanted. Calves were housed in dry-lot pens equipped with a single bale feeder allowing 81 m$^2$ per calf. Access restriction for TIME cattle was conducted with polywire pen division. Two day initial and final full body weights were collected with interim weights collected in 28 d increments over a 91 d experiment. Ad libitum forage access was allowed 5 d prior to final body weight collection.

Large round bales were offered whenever visually appraised forage remaining in the feeder was estimated to limit intake in the following day. Feeders were not moved for the experiment duration. Weight and three core samples were collect from each fescue bale to determine quality and DM (87.4% DM, 10.9% CP, 61.9% NDF, 36.0% ADF). Forage remaining in the feeder was weighed upon experiment completion and sampled for DM determination to calculate pen forage disappearance. Forage samples were analyzed using a FOSS XDS monochromator XM-1000 fitted with a XDS rapid content analyzer XM-1100 (FOSS NIRSystems Inc.; Laurel, MD). Wet chemistry methods were used to generate forage quality prediction equations. Resulting $R^2$ for DM, CP, NDF, ADF and ash predictions were 0.81, 0.89, 0.93, 0.86, and 0.55 respectively.

Calves were offered a lasalocid containing (85 g/909 kg) supplement composed of dried distillers grains with solubles, cracked corn, and ground sorghum grain at 2.8 kg• calf$^{-1}$• d$^{-1}$ corresponding to 1.02% initial body weight (Table 3.1). Supplement offered was divided equally into morning and evening feedings just prior to and following limited access to large round bales. Supplement nutrient composition was determined using wet chemistry methods (Table 3.1).

Data were analyzed as a randomized complete block design using pen as the experimental unit. All differences were determined using Fishers Least Significant
Difference from the LSMEANS statement in PROC MIXED of SAS 9.3 (SAS Inst. Inc.; Cary, NC). Treatments were considered to be different at $\alpha \leq 0.05$.

RESULTS AND DISCUSSION

Experiment 1

Heifer Weight and BWG. Forage disappearance and heifer performance are summarized in Table 3.2. Heifers were heavier ($P < 0.01$) in yr. 1 than yr. 2 at experiment initiation. An access time by year interaction was observed for final body weight ($P < 0.01$) where reducing access time reduced final body weight in yr. 1 ($P < 0.01$) but not in yr. 2 ($P = 0.10$). These results are consistent with results by Miller et al. (2007) and Cunningham et al. (2005) where cow performance varied with access time but performance was numerically lower for RAT fed cows in most scenarios. Similarly, 24HR heifer ADG was numerically greater than 8HR in yr. 1 (0.93 vs. 0.77 kg ADG) and yr. 2 (0.81 vs. 0.76 kg ADG). Year and access time tended ($P = 0.08$) to interact as ADG was greater ($P < 0.01$) for 24HR in yr. 1 while in yr. 2 ADG was not different ($P = 0.11$) for 24HR and 8HR access times.

Forage Disappearance and Utilization. In agreement with Cunningham et al. (2005) and Miller et al. (2007), RAT reduced ($P < 0.01$) forage DM disappearance. Daily forage disappearance in kilograms per heifer was reduced 10% with 8HR heifers and tended to be greater ($P < 0.10$) in yr. 1 than yr. 2 but this was explained by greater initial
body weight in yr. 1 as forage disappearance expressed as a percent of body weight was not different ($P = 0.80$) due to year. In yr. 1, ADG was reduced 17% in 8HR heifers while forage disappearance was reduced by 9.7% suggesting minimal reduction in wasted forage when forage access was restricted. In yr. 2, ADG was reduced 6.2% with a 10.7% decrease in forage disappearance. These results suggest as intake is limited so is performance which agrees with linear reductions in performance seen as access time is restricted (Cunningham et al., 2005; Miller et al., 2007).

Forage intake was predicted from calculated midpoint body weight and observed growth rate according to NRC (2000) equations where maintenance energy requirements were 77 Kcal/ BW$^{0.75}$ and retained energy for growth was calculated from empty body weight (EBW) and EBW gain (NRC, 2000). Forage net energy for maintenance and gain were calculated from measured ADF percent (Schroeder, 1994). Dried distillers grains with solubles net energy for maintenance and gain were obtained from Loy et al. (2008). Based on predicted forage intake, waste as a percent of forage DMI was not different ($P = 0.39$) due to access time but averaged 25.3% for 8HR and 21.9% for 24HR. Predicted waste estimates agree with 19 to 22% waste observed by Moore (2013) and Sexten (2011) with ad libitum cow access to open bottom feeders suggesting RAT to open bottom feeders does not reduce forage waste.

An access time by year interaction tended ($P = 0.09$) to exist for total gain to feed (forage disappearance plus supplement offered) as 24HR heifers in yr. 1 were more efficient ($P = 0.06$) than 8HR heifers but feed efficiency was not different ($P = 0.69$) in yr. 2. Gain to feed was considered a forage use efficiency measure as forage quality and supplement feed were not different due to treatment so improved efficiency was assumed
a reduction in forage waste. Gain to feed results suggest restricting access time was not
effective at reducing waste or increasing DM digestibility in developing heifers although
direct waste or digestibility measures were not collected. Results disagree with previous
research where RAT to 6 and 9 hours numerically reduced waste as a percent of DMI
(Miller et al., 2007). Disagreement with previous research could be the difference in calf
and cow feeding behavior. Additionally, in research by Miller et al. (2007) and
Cunningham et al. (2005), forage was the only nutrient source offered to gestating and
lactating cows where a supplement was offered in the current experiment. In a system
with supplemental feed, perhaps access time should be shortened to reduce waste due to
less forage energy intake required.

Although gain and intake were reduced in both years, target weights (> 60% of
mature BW) were achieved 30 d prior to schedule breeding. Mean pelvic area measures
(198 cm² for 8HR, 193 cm² for 24HR) were not different (P = 0.18) due to access time.
Additionally, mean reproductive tract scores (4.10 for 8HR, 4.07 for 24HR) were not
different (P = 0.84) due to access time. These results suggest RAT can reduce forage
requirements for a heifer development program with no impact on pre-breeding
reproductive development.

Experiment 2

Calf Weight and BWG. Forage disappearance, forage use efficiency, predicted
intake and calf performance data are summarized in Table 3.3. Access time and feeder
impacted (P = 0.05) ADG where CONE resulted in greater (P = 0.02) ADG (1.11 kg/d)
than TIME (1.00 kg/d) and tended (P = 0.10) to result in greater ADG than OPEN (1.04
kg/d). ADG was not different (P = 0.24) for OPEN and TIME suggesting RAT did not
affect performance when compared to cattle fed in a standard large round bale feeder with *ad libitum* access. These results agree with those of Miller et al. (2007) who noted no difference in gestating cow performance with 6, 9 or 24 access hours to moderate quality hay although body weight gain was numerically lower with RAT. Numerically, ADG was reduced 3.9% for TIME compared to OPEN which is less than 6.4 and 19.1% reductions for nine and six restriction hours respectively observed by Miller et al. (2007). These differences are likely due to high supplementation levels (1.02% BW) in the current experiment where calves were less dependent on forage energy intake for performance. Additionally, Miller et al. (2007) observed increasing DMI with increasing access time but noticed digestibility was numerically greater with less access time explaining no difference in body weight gain due to access time. Greater BWG for CONE treatment were not explained by forage quality offered as CP, NDF, ADF, and ash were not different (*P > 0.10*) due to treatment. Additionally forage offered was not different (*P = 0.67*) for CONE (5,507 kg) and OPEN (5,462 kg) but was reduced (*P < 0.01*) for TIME (4,672 kg). Supplement level was constant across treatments suggesting addition gains were a product of increased forage intake or improved efficiency.

*Forage Disappearance.* Daily forage disappearance and disappearance as a percent of body weight were less (*P < 0.01*) for TIME (4.09 kg/d or 1.28% BW) compared to OPEN (4.74 kg/d or 1.47% BW) and CONE (4.82 kg/d or 1.48% BW) which were not different (*P > 0.50*). Forage disappearance decreased 13% for TIME compared to CONE and OPEN which is comparable to 10% reduction observed in Experiment 1. These results agree with those of Miller et al. (2007) and Cunningham et al. (2005) who observed DMI decreased linearly with decreasing access time. However,
these results disagree with those by Sexten (2011) where cone-type feeder resulted in less forage disappearance (intake plus waste) than open bottom feeders. However, greater ADG for CONE compared to OPEN with no difference in forage disappearance suggests forage intake was a greater proportion of disappearance for CONE than OPEN and waste was greater with the OPEN feeder if opportunity for feed efficiency was assumed to be equal due to similar calf genetics and environment.

*Predicted Forage Waste.* Intake was predicted based on calculated midpoint body weight and observed growth rate to further explain waste differences. Maintenance energy required was assumed at 77 Kcal/ BW\(^{0.75}\) (NRC, 2000). Retained energy required for growth was calculated from empty body weight (EBW) and EBW gain (NRC, 2000). Forage net energy for maintenance and gain was calculated from measured ADF (Schroeder, 1994). Supplement net energy for maintenance and gain was calculated from values presented by NRC (2000) with an adjustment for dried distillers grains with solubles energy value (Loy et al., 2008). Net energy of maintenance for both feeds was increased by 12% due to ionophore use. Predicted forage DMI was greater \((P = 0.04)\) for CONE (4.40 kg) compared to TIME (3.66 kg) and tended \((P = 0.14)\) to be greater than OPEN (3.94 kg). Based on DMI predictions, waste reductions were 50.6 and 40.4% for CONE and TIME respectively compared to OPEN. Waste reductions for CONE were less than previous observations by Sexten (2011) were cone type feeder resulted in 73% less waste than open bottom feeder. Cone feeder hay saving features may have not been realized to the extent since bale feeders were not moved or orts within the feeder were not removed and the sheeted bottom would eventually fill with refused forage. In the current experiment, cone feeder waste was 10% which is greater than 4, 2 and 5% waste
observed with similar forage fed in cone type feeders to cows (Buskirk et al., 2003; Comerford, 1994; Sexten, 2011). Increased CONE waste in the current experiment could be differences in calf feeding behavior or waste estimates in a continuous feeding system. In the current experiment, calves were observed entering the cone feeder which could increase waste due to forage contamination within the feeder. Cone feeder and RAT with a standard feeder were both effective at reducing forage waste with no effect on growing calf performance.

**IMPLICATIONS**

Eight access hours to large round bales reduces forage disappearance by 10 to 13% with developing heifers and growing calves. In a winter feeding system where maximal calf performance may not be desired, RAT is an effective tool to reduce forage use with minimal infrastructure investment. RAT can reduce growing cattle body weight gain. *Ad libitum* access to a cone feeder and restricting forage access with an open bottom feeder resulted in less forage usage per unit of gain compared to open feeders and resulted in comparable waste reductions to limiting access time.
<table>
<thead>
<tr>
<th>Item</th>
<th>Exp. 1</th>
<th>Exp. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dried distillers grains with solubles</td>
<td>93.7</td>
<td>46.8</td>
</tr>
<tr>
<td>Cracked corn</td>
<td>.</td>
<td>15.3</td>
</tr>
<tr>
<td>Ground sorghum grain</td>
<td>.</td>
<td>30.7</td>
</tr>
<tr>
<td>Mineral premix(^1)</td>
<td>6.3</td>
<td>7.1</td>
</tr>
<tr>
<td>CP</td>
<td>24.9</td>
<td>22.2</td>
</tr>
<tr>
<td>Crude fat</td>
<td>11.2</td>
<td>.</td>
</tr>
<tr>
<td>NDF</td>
<td>.</td>
<td>27.8</td>
</tr>
<tr>
<td>ADF</td>
<td>7.1</td>
<td>9.0</td>
</tr>
<tr>
<td>Ash</td>
<td>7.8</td>
<td>6.3</td>
</tr>
</tbody>
</table>

\(^1\)Experiment 1: 26% Ca, 3.5% P, 1.7% Na, 1.1% Mg, 0.6% K, 875 ppm Cu, 9.1 ppm Se, 195 ppm Fe, 195 ppm Mn, 77000 IU/kg Vitamin A, 7700 IU/kg Vitamin D, 77 IU/kg Vitamin E

Experiment 2: 29.3% Ca, 9.4% NaCl, 2.0% K, 220000 IU/kg Vitamin A, 33000 IU/kg Vitamin D, 440 IU/kg, 1200 g/ 909 kg lasalocid
### Table 3.2: Exp. 1 heifer performance and forage disappearance

<table>
<thead>
<tr>
<th>Item</th>
<th>Year 1</th>
<th>Year 2</th>
<th>SEM$^3$</th>
<th>$P$-value$^1$</th>
<th>Time</th>
<th>Year</th>
<th>Time x Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8 HR$^2$</td>
<td>24 HR</td>
<td>8 HR</td>
<td>24 HR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial BW, kg</td>
<td>327.1$^a$</td>
<td>326.3$^a$</td>
<td>315.1$^b$</td>
<td>313.9$^b$</td>
<td>2.79</td>
<td>0.62</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Final BW, kg</td>
<td>409.9$^b$</td>
<td>425.3$^a$</td>
<td>385.2$^c$</td>
<td>389.5$^c$</td>
<td>2.66</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>ADG, kg/d</td>
<td>0.77$^b$</td>
<td>0.93$^a$</td>
<td>0.76$^b$</td>
<td>0.81$^b$</td>
<td>0.04</td>
<td>&lt;0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Forage Disappearance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total, kg/head$^4$</td>
<td>734.3$^b$</td>
<td>830.3$^a$</td>
<td>590.7$^c$</td>
<td>657.5$^d$</td>
<td>37.6</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Daily, kg/head$^5$</td>
<td>6.86$^a$</td>
<td>7.77$^b$</td>
<td>6.50$^a$</td>
<td>7.23$^b$</td>
<td>0.38</td>
<td>&lt;0.01</td>
<td>0.09</td>
</tr>
<tr>
<td>% BW$^6$</td>
<td>1.87$^a$</td>
<td>2.07$^b$</td>
<td>1.84$^a$</td>
<td>2.06$^b$</td>
<td>0.11</td>
<td>0.01</td>
<td>0.80</td>
</tr>
<tr>
<td>Total G:F</td>
<td>0.087$^b$</td>
<td>0.095$^a$</td>
<td>0.089$^b$</td>
<td>0.088$^b$</td>
<td>0.004</td>
<td>0.21</td>
<td>0.28</td>
</tr>
</tbody>
</table>

$^1$ Observed significance level for access time, year and the interaction of time and year

$^2$ Treatments: 8HR= 8 hour forage access, 24HR= *ad libitum* forage access

$^3$ Largest standard error of least squared means

$^4$ Total forage disappearance in kg per heifer

$^5$ Forage disappearance expressed as kg per heifer per d

$^6$ Daily Forage disappearance as a percent of calculated midpoint body weight
<table>
<thead>
<tr>
<th>Item</th>
<th>Time</th>
<th>Cone</th>
<th>Open</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial wt., kg</td>
<td>275.4</td>
<td>277.3</td>
<td>274.9</td>
<td>3.03</td>
<td>0.72</td>
</tr>
<tr>
<td>Final wt., kg</td>
<td>366.5</td>
<td>377.9</td>
<td>369.7</td>
<td>5.03</td>
<td>0.14</td>
</tr>
<tr>
<td>ADG, kg</td>
<td>1.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.11&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.04&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>Daily forage disappearance per calf</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>kg</td>
<td>4.09&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.82&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.74&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.11</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>% BW&lt;sup&gt;3&lt;/sup&gt;</td>
<td>1.28&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.48&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.47&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.02</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Forage G:F&lt;sup&gt;4&lt;/sup&gt;</td>
<td>0.245&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.230&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.219&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.008</td>
<td>0.05</td>
</tr>
<tr>
<td>Predicted Forage Intake&lt;sup&gt;5&lt;/sup&gt;, kg/d</td>
<td>3.66&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.40&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.94&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.27</td>
<td>0.09</td>
</tr>
<tr>
<td>Waste&lt;sup&gt;6&lt;/sup&gt;, % DMI</td>
<td>12.35</td>
<td>10.21</td>
<td>20.69</td>
<td>6.21</td>
<td>0.28</td>
</tr>
</tbody>
</table>

<sup>1</sup> Treatments: Time= 8 hours forage access, Cone= <em>ad libitum</em> access to cone feeder, Open= <em>ad libitum</em> access to open feeder  
<sup>2</sup> Observed significance level for treatment effect  
<sup>3</sup> Daily forage disappearance as a percent of calculated middle body weight  
<sup>4</sup> Gain to feed ratio expressed as kg gain: kg forage intake  
<sup>5</sup> Forage intake calculated from observed ADG and supplement energy intake  
<sup>6</sup> Calculated waste as percent of predicted forage intake [(forage disappearance-predicted intake)/predicted intake]
**Figure 3.1**: Open feeder used in Exp. 1 & 2
Figure 3.2: Cone feeder used in Exp. 2
CHAPTER 4

EFFECT OF FEEDER DESIGN AND AMMONIATION ON CORN STOVER WASTE AND SORTING

ABSTRACT

Thirty-six non-lactating, open crossbred cows were used in two simultaneous 3 X 3 Latin squares to evaluate the effect three bale feeders on waste of corn stover (CS) or ammoniated corn stover (ACS) bales. Cows were stratified by age (4 ± 1.8 yrs), weight (518 ± 55 kg), and BCS (5.4 ± 0.4 units) into six replicates. Bale feeders evaluated for both experiments were open bottom with 17 slanted feeding stations (Open) (2.4 m diam., 1.2 m height), sheeted bottom with 15 slanted feeding stations and tapering sides (Taper) (2.1 m diam. top, 2.4 m diam. bottom, 1.2 m height, 0.5 m sheeting), and sheeted bottom and top with 16 straight feeding stations and chain cone (Cone) (2.3 m diam., 1.7 m height, 0.6 m bottom sheeting, 0.5 m top sheeting). Separate lots of purchased CS bales were barn stored (1.6 m height, 1.7 m diam., 480 ± 27 kg DM) (Exp. 1) or ammoniated at 3.17% DM (1.2 m height, 1.5 m diam., 274 ± 23 kg DM) (Exp. 2). Monensin containing mineral supplement was fed at 0.45 kg•head⁻¹•d⁻¹ for both experiments and CS cows received an additional 2.18 kg•head⁻¹•d⁻¹ dried distillers grains plus solubles. We hypothesized cone and sheeting would reduce waste and ammoniation would reduce
waste due to less leaf and husk selective consumption. **Exp. 1:** Waste as a percent of bale weight tended ($P = 0.12$) to be less for cone (13.0%) compared to open (38.5%). Taper waste (31.7%) was intermediate and not different from cone ($P = 0.11$) or open ($P = 0.42$). An interaction ($P < 0.01$) was observed for feeder and day where cone (2.4%) resulted in less waste at 24 h than open (20.7%) and taper (21.5%) while 48 and 72 h waste was not different by feeder ($P > 0.10$). **Exp. 2:** Waste as a percent of bale weight was greatest ($P = 0.03$) for open (37.9%) compared to cone (13.6%) and taper (20.6%) which were not different ($P = 0.15$). An interaction for waste ($P = 0.04$) was observed for feeder and day where cone (5.7%) resulted in less waste ($P = 0.01$) at 24 h than open (22.4%) and taper (17.0%) which were not different ($P = 0.14$). At 48 h, waste as a percent of bale weight was greater ($P = 0.05$) for open (15.5%) compared to cone (7.9%) and taper (3.6%) which were not different ($P = 0.21$). Sorting occurred for both CS and ACS where ADF was 5.5% greater ($P < 0.01$) in orts than initial bale. Cone was effective at reducing waste with CS while cone and taper reduced waste with ACS. Ammoniation was not effective at reducing waste or stalk sorting.

**INTRODUCTION**

In the last decade, acres harvest for hay have decreased 5%, hay production has decreased 11%, and price paid for hay has increased 77% (NASS, 2013). In the same time period, corn acres planted have increased 20% (NASS, 2013). Increased corn stover
(CS) availability makes it a viable forage alternative. However, little is known regarding CS bale feeding waste in a ring feeder with \textit{ad libitum} access.

Large round bale feeders use is the most adopted stored forage feeding method for Oklahoma beef producers (Sexten, 2011). Bale feeder design has been shown to impact hay waste by altering agonistic interactions, entrance frequency (regular and irregular) and feeder occupancy (Buskirk et al., 2003). Ring feeders allow cattle to eat in a natural grazing position which prevents hay loss from infrequent entrances (Buskirk et al., 2003). Cone-type feeders also reduce hay waste by providing a larger feeding area inside the feeder (Buskirk et al., 2003; Landblom et al., 2007; Sexten, 2011). Waste associated with CS bale feeding in ring feeders has never been documented.

Anhydrous ammonia treatment of low quality forage improves DM digestibility and DMI by supplying adequate rumen degradable nitrogen (Buettner et al., 1982; Paterson et al., 1981; Zorrilla-Rios et al., 1991). Stalk is the least digestible CS component and composes approximately 50\% corn plant residue following grain harvest (Pordesimo, 2004; Shinners, 2007). CS is a good candidate for ammoniation as the poor digestible fractions also contain the most moisture, concentrating the anhydrous ammonia in the components with the greatest proportion of structural carbohydrates (Weaver et al., 1978). Increased stalk pliability from ester bonds reduction could also increase stalk palatability and reduce the leaf selective consumption. Non-protein nitrogen addition to low quality forage could increase DMI without providing supplemental feed.

The objective of these experiments was to quantify feeding waste using three bale feeder designs with ammoniated or non-ammoniated CS. We hypothesize feeding CS in
ring feeders will result in greater waste than previous reports for grass hay and ammoniation will reduce CS wasted.

MATERIALS AND METHODS

Experiment 1

Eighteen non-lactating, open crossbred cows were used in a 3 X 3 Latin square with three bale feeder designs to determine the effect of bale feeder on corn stover (CS) waste. Cows were stratified by 24 h shrunk BW (520 ± 59.2 kg), BCS (5.4 ± 0.5 units), and age (4.3 ± 1.6 years) into three replicates with six head per replicate. Each replicate was randomly assigned to one of three, 16.6 X 7.3 m concrete pens with 4.5 m bunk space. Facilities were open to the south and forage sampling pad was 8.8 X 7.3 m with the remainder of the pen covered and bedded with sawdust. Bale feeders were rotated upon nine day sampling period completion. Experimental duration was 40 d with 24 h fasted BW and BCS collected at the beginning and end. Fasted BCS were assigned on a 1 to 9 scale (1 = extremely thin, 9 = obese) by two experienced evaluators.

Three bale feeder designs were open, taper, and cone (Figure 4.1). Open was non-sheeted at the bottom, 2.4 m in diam. and 1.2 m in height. Taper had 0.5 m straight bottom sheeting and measured 2.4 m bottom diam., 2.1 m top diam. and 1.2 m height. Cone was 2.3 m in diameter, 1.7 m in height, and had 0.6 m bottom sheeting, 0.5 m top
sheeting and a 16 chain cone spaced at 41 cm. Feeding spaces for open feeder \( (n = 17) \) were 41 cm wide and 65 cm tall and bars were oriented at 73 degree angle. Cone dividers were oriented at 90 degree with feeding space \( (n = 16) \) 41 cm wide and 69 cm tall. Taper feeder dividing bars were oriented at 74 degree angle with a feeding space \( (n = 15) \) 46 cm in wide and 66 cm tall.

Monensin containing mineral supplement (Table 4.1) \( (200 \text{ mg\textcdot cow}^{-1}\text{\cdot d}^{-1} \) monensin) was offered at 0.45 kg with 2.18 kg dried distillers grains plus solubles\textcdot cow\textcdot d\textsuperscript{-1} to meet degradable intake protein requirements. Purchased CS bales measured 1.6 m in height and 1.7 m in diam. and had an average DM weight of 480 ± 27 kg (Table 4.2). CS bales were barn stored prior to feeding.

During CS feeding period, one bale was provided for acclimation to feeder design. At 72 h, orts and debris were cleaned from feeding pad and a new bale was added. Waste was collected at 24, 48, and 72 h following new bale introduction. At 72 h, orts were removed from feeder, weighed and sampled. Following orts removal, two additional bales were provided for waste collection replication. Waste was considered forage outside the bale ring. Orts were forage remaining in the feeder. Waste was divided into potentially contaminated and clean forage. Clean forage was manure and urine free while potentially contaminated waste was either wet or contaminated with manure which could not be removed during collection. Waste subgroups were then sub-sampled and weighed for DM determination and analyzed for CP, NDF, ADF, and ash. Total DM waste estimates, NDF, ADF, and ash were composited as a weighted means for calculations and statistical analysis.
CS samples were immediately dried at 55º C for 48 h, ground through a 5 mm screen in a Wiley Mill (Model 4, Thomas Scientific; Sweedesboro, NJ), subsampled and ground through a 1 mm screen using a 1093 Cyclotech Mill (Tecator; Eden Prairie, MN 55344). Ground samples were placed in sealed plastic cup and stored at 2º C until analysis. Wet chemistry methods were used for DM (dried 16 h at 100º C), CP (% N X 6.25; FP-428 LECO Corporation; St. Joseph, MI 49085), NDF and ADF (Ankom Tech Corp; Fairport, NY) and ash (combusted 8 h in a muffle furnace at 500º C) for all samples.

Experiment 2

Eighteen open Angus cross cows were used in a 3 X 3 Latin square with three bale feeder designs to determine the effect of bale feeder on ammoniated corn stover (ACS) waste. Cows were stratified by 24 h shrunk BW (516 ± 51.8 kg), BCS (5.4 ± 0.3 units), and age (4.2 ± 2.0 years) into three replicates with six head per replicate. Facilities and feeder rotation were as described in Exp. 1. Three bale feeder designs were identical to Exp. 1 (Figure 4.1). Monensin containing mineral supplement was offered at 0.45 kg•head\textsuperscript{-1}•d\textsuperscript{-1}. Experimental duration was 25 d with 24 h shrunk BW and BCS collected at the beginning and end.

Ammoniation was conducted on September 7\textsuperscript{th} 2012 and was as follows: bales were stacked three high in pyramid on 20 cm of crushed limestone, covered with 8 mm black plastic, plastic edges were sealed using topsoil, anhydrous ammonia was applied at a rate of 3.17% (DM Basis) over a 4 h duration. Ammoniated hay stack was un-sealed 104 d later and allowed to vent for 28 d prior to feeding. ACS bales were 1.2 m in height.
and 1.5 m in diameter and had an average DM weight of 274 ± 23 kg (Table 4.2). During each sampling period, one bale was provided for feeder acclimation, at 48 h, orts and debris were cleaned from feeding pad and a new bale offered. Waste was collected at 24 and 48 h following new bale introduction. At 48 h, orts were removed from feeder, weighed and sampled, and two replicate collection bales continued. Waste, orts, and bale sampling methods were the same as described in Exp. 1. Forage sample handling and analysis was identical to Exp. 1.

Statistical Analysis

Analysis one was performed as a 3 X 3 Latin square. Treatments were bale feeders (n = 3). Columns represented three pens and rows represented three periods. Pen was the experimental unit and bale within period was considered a pseudo-replicate. Analysis two, parameters taken over time for Exp. 1 (24, 48, and 72 h) and Exp. 2 (24 and 48 h) were analyzed as a 3 X 3 Latin square with repeated measurement. The main plot contained the effect of column, row, and feeder. The subplot contained the effects of time and all interactions with feeder. Analysis three was similar to analysis two except measures (CP, ADF, NDF, and ash) were analyzed by component (bale, waste, and orts) instead of over time. All differences were determined using Fishers Least Significant Difference from the LSMEANS statement in PROC MIXED of SAS 9.3 (SAS Inst. Inc.; Cary, NC). Treatments were considered to be different at α ≤ 0.05.
RESULTS AND DISCUSSION

Experiment 1

Results for CS waste, ors and intake for Exp. 1 are shown in Table 4.3. Waste as a percent of bale tended ($P = 0.12$) to be different due to feeder where cone resulted in three times less waste (13.0%) than open (38.5%). Taper (31.7%) was intermediate but not different from cone and open. Calculated CS DMI as a percent of BW was not different ($P = 0.79$) due to feeder. Predicted forage DMI as a percent of body weight was 1.98% which is in the calculated DMI range (1.94 to 2.08%) observed in this experiment suggesting feeder designs did not restrict DMI (NRC, 2000). Waste as a percent of DMI was not different due to feeder ($P = 0.20$) although numerical range was from 31.9% for cone to 108.1% for open suggesting large waste estimate variability. Measured variability in this experiment was caused by inconsistency in purchased CS bales composition as visual observation suggest drainage ditches were baled into some CS bales increasing bale density and reducing waste. Variability in bales was not observed in forage quality analysis. These results agree with previous research were cone-type feeders resulted in less waste than open ring feeder (Buskirk et al., 2003; Comerford, 1994; Sexten, 2011).

A feeder by day interaction for waste as a percent of bale weight ($P < 0.01$) was observed (Figure 4.2) where cone (2.4%) resulted in less waste at 24 h than open (20.7%) and taper (21.5%). At 48 and 72 h, waste as a percent of bale weight, was not different due to feeder ($P > 0.10$) although there was a trend ($P = 0.11$) for cone (5.5%) to result in
less waste than open (10.5%) at 48 h. Difference in waste by hour can be explained by cone feeder providing a larger feeding spacing within the feeder allowing feeding waste to remain in the protective sheeting in the feeder early in the feeding period. However, as the bale loses structure and is no longer suspended in chains and the protective sheeting fills with forage, waste was not different ($P = 0.45$) from open and taper at 72 h.

Feeder did not effect ($P > 0.50$) sorting however sorting was evident by component (Table 4.5). Waste had greater ($P < 0.01$) ADF and lower ash when compared to bale measures. Moreover, orts contained lower ($P < 0.02$) CP and ash, while ADF was greater ($P < 0.01$) suggesting stalk proportion in orts and waste were greater than the initial bale. These results agree with previous research by Methu et al. (2001) who reported lower ash and CP concentrations with higher ADF concentration in maize stems compared to leaves. Methu et al. (2001) also observed increases in the amount of leaf to stem consumed as daily DM offerings increased from 3.0 to 8.6% BW suggesting an ad libitum corn stover offering increases the incidence of selective stover leaf consumption.

Experiment 2

Results for ACS waste, orts and intake for Exp. 2 are show in Table 4.4. Feeder affected ($P = 0.03$) waste as a percent of bale weight where open resulted in greater waste (37.9%) compared to cone (13.6%) and taper (20.6%). Calculated DMI as a percent of body weight was not different ($P = 0.59$) due to feeder and ranged from 2.05 to 2.29% which is greater than predicted DMI (1.98% BW) suggesting feeder designs in this experiment did not restrict DMI (NRC, 2000). Greater than predicted ammoniated CS DMI is likely caused by increased forage OM digestibility due to ammoniation
(Brown et al., 1987). Due to no difference in DMI and greater waste, orts were lower ($P = 0.03$) for open compared to cone and taper. Waste as a percent of DMI tended ($P = 0.07$) to be different by feeder where open was greatest (78.6%), taper was intermediate and not different from cone or open, and cone was least (29.3%). These results agree with previous research were cone-type feeder resulted in less waste than open ring feeder (Buskirk et al., 2003; Sexten, 2011).

A feeder by day interaction for waste as a percent of bale weight ($P = 0.04$) was observed (Figure 4.3) where cone (5.7%) resulted in less waste ($P = 0.01$) at 24 h than open (22.4%) and taper (17.0%) which were not different ($P = 0.14$). At 48 h, waste as a percent of bale weight was greater ($P = 0.05$) for open (15.5%) compared to cone (7.9%) and taper (3.6%) which were not different ($P = 0.21$). These results indicate the cone reduced waste early in the feeding period because the bale maintained form and was suspended in the cone. At 48 h, forage remaining above the cone was minimal, suggesting hay savings for cone and taper were comparable due to sheeting. Additional forage waste at 48 h for open can be explained by continued forage loss from the bottom (non-sheeted) portion of the feeder.

Feeder did not affect ($P = 0.19$) sorting however sorting was evident by component (Table 4.6) where waste had greater ($P < 0.01$) ADF and NDF with lower ($P < 0.01$) ash and CP than bale. Orts contained lower ($P < 0.01$) CP and ash, while ADF and NDF were greater ($P < 0.01$) suggesting stalk proportions were greater in orts and waste than the initial bale (Methu et al., 2001).
Overall

Previous waste reports during grass hay feeding ranged from 3.5 to 22% depending on feeder design (Baxter et al., 1986; Buskirk et al., 2003; Sexten, 2011). In the current study CS and ACS waste ranged from 13.0 to 38.5% of bale weight which is similar to 21% refusals measured by Osafo et al. (1997) who offered grain sorghum stover at 2.4% BW. CS results in greater forage waste compared to grass hay especially when feeders do not possess hay saving features as cone CS waste was 10% units higher than cone grass hay waste reports while open CS waste was 16.5% units higher than open grass hay waste reports. Based on previous grass hay waste observations reported by Sexten (2011) and Moore (2013), corn stover waste during feeding is approximately twice grass hay waste.

Because differences in bale size, harvest technique, and experiment duration existed between the two projects, statistical comparisons were not possible. However, waste as a percent of bale weight was numerically similar for CS (13.0 to 38.5%) and ACS (13.6 to 37.9%). Orts were numerically greater in Exp. 1 than Exp. 2 indicating disappearance as a percent of the bale was greater for ACS than CS. Average waste as a percent of DMI was 50.3% for ACS while CS was 71.3% which suggests a reduction in waste due to ammoniation. However similar waste with cone feeder (31.9 vs. 29.3% DMI) might suggest numerical differences for taper and open are more likely credited to differences in bale size than ammoniation. Regardless of feeder, sorting was present in both experiments suggesting ammoniation of CS does not improve palatability of corn stalk with *ad libitum* access and no forage processing.
ADG for cows consuming ACS was 0.83 ± 0.13 kg with a 0.4 unit increase in BCS. ADG for cows consuming CS plus dried distillers grains plus solubles was 0.97 ± 0.04 kg with a 0.5 unit increase in BCS. These limited performance data suggest ACS and CS plus DDGS are both acceptable options for adding weight to non-lactating open cows.

**IMPLICATIONS**

As hypothesized, bale feeder influenced forage waste where cone resulted in the least waste amount and open resulted in the greatest waste amount in both experiments. Cone feeder reduced CS and ACS waste 65% compared to open feeder while taper reduces CS and ACS waste by 18 and 46% respectively. In opposition to the hypothesis, ammoniation was not effective at reducing waste or selective leaf consumption with corn stover. Future research is needed to determine optimal bale to feeder size and feeder stocking density to reduce hay waste.
Table 4.1. DM supplement composition

<table>
<thead>
<tr>
<th>Item, % DM</th>
<th>Supplement</th>
<th>Item, % DM</th>
<th>Supplement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat Middlings</td>
<td>6.2</td>
<td>DM</td>
<td>90.4</td>
</tr>
<tr>
<td>Ground Corn</td>
<td>18.5</td>
<td>CP</td>
<td>19.7</td>
</tr>
<tr>
<td>Soybean Meal</td>
<td>38.4</td>
<td>NDF</td>
<td>21.2</td>
</tr>
<tr>
<td>Salt</td>
<td>5.4</td>
<td>ADF</td>
<td>5.5</td>
</tr>
<tr>
<td>Limestone</td>
<td>6.4</td>
<td>Ash</td>
<td>39.0</td>
</tr>
<tr>
<td>Dicalcium Phosphate</td>
<td>8.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnesium Oxide</td>
<td>8.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamin and Mineral Premix$^a$</td>
<td>8.3</td>
<td>Monensin, g/ 909 kg</td>
<td>400 g</td>
</tr>
</tbody>
</table>

$^a$ Vitamin and Mineral Premix = 26.0% trace mineral premix (3.0% Zn, 2.5% Fe, 2.0% Mn, 1.0% Cu, 100 ppm Co, 500 ppm I, 100 ppm Se), 9.1% vitamin premix (8,800,000 IU/kg vitamin A, 1,760,000 IU/kg vitamin D, 1,100 IU/kg vitamin E) and 64.9% vitamin E premix (4,400 IU/kg)
Table 4.2. Forage nutrient composition (DM Basis) and bale size

<table>
<thead>
<tr>
<th>Item</th>
<th>Corn Stover (Exp. 1)</th>
<th>Ammoniated(^a) Corn Stover (Exp. 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td>91.5</td>
<td>81.3</td>
</tr>
<tr>
<td>CP</td>
<td>4.6</td>
<td>13.3</td>
</tr>
<tr>
<td>NDF</td>
<td>77.5</td>
<td>75.7</td>
</tr>
<tr>
<td>ADF</td>
<td>48.2</td>
<td>48.1</td>
</tr>
<tr>
<td>Ash</td>
<td>9.2</td>
<td>7.7</td>
</tr>
<tr>
<td>Bale diam., m</td>
<td>1.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Bale height, m</td>
<td>1.6</td>
<td>1.2</td>
</tr>
<tr>
<td>Bale wt., kg</td>
<td>480</td>
<td>274</td>
</tr>
</tbody>
</table>

\(^a\) Anhydrous ammonia (NH\(_3\)) applied at 3.17% DM basis
Table 4.3. Effect of bale feeder design on corn stover waste

<table>
<thead>
<tr>
<th>Item</th>
<th>Cone</th>
<th>Taper</th>
<th>Open</th>
<th>SEM²</th>
<th>P-value³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bale wt., kg</td>
<td>484.9</td>
<td>473.8</td>
<td>476.9</td>
<td>12.9</td>
<td>0.72</td>
</tr>
<tr>
<td>Waste, kg</td>
<td>63.2b</td>
<td>150.4a</td>
<td>183.8a</td>
<td>29.7</td>
<td>0.11</td>
</tr>
<tr>
<td>Orts, kg</td>
<td>213.4</td>
<td>133.5</td>
<td>108.1</td>
<td>34.6</td>
<td>0.17</td>
</tr>
<tr>
<td>Waste, % bale</td>
<td>13.0b</td>
<td>31.7ab</td>
<td>38.5a</td>
<td>6.65</td>
<td>0.12</td>
</tr>
<tr>
<td>Waste, %</td>
<td>31.9</td>
<td>79.1</td>
<td>102.8</td>
<td>25.4</td>
<td>0.20</td>
</tr>
<tr>
<td>DMI, %</td>
<td>2.08</td>
<td>2.00</td>
<td>1.94</td>
<td>1.19</td>
<td>0.79</td>
</tr>
</tbody>
</table>

1 Cone = chain cone with top and bottom sheeting, Taper = straight bottom sheeting and tapering to top, Open = no sheeting
2 Largest standard error of least squared means
3 Observed significance levels for main effect of feeder
4 Forage waste expressed as a percentage of DM bale weight
5 Forage waste expressed as a percentage of calculated total forage intake
6 Average daily forage intake expressed as a percent of calculated midpoint body weight
Table 4.4. Effect of bale feeder design on ammoniated corn stover waste

<table>
<thead>
<tr>
<th>Item</th>
<th>Cone</th>
<th>Taper</th>
<th>Open</th>
<th>SEM²</th>
<th>P-value³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bale wt., kg</td>
<td>263.3</td>
<td>275.8</td>
<td>283.3</td>
<td>10.0</td>
<td>0.33</td>
</tr>
<tr>
<td>Waste, kg</td>
<td>35.6ᵇ</td>
<td>56.9ᵇ</td>
<td>106.2ᵃ</td>
<td>7.81</td>
<td>0.02</td>
</tr>
<tr>
<td>Orts, kg</td>
<td>98.1ᵇ</td>
<td>83.6ᵇ</td>
<td>32.9ᵃ</td>
<td>7.78</td>
<td>0.03</td>
</tr>
<tr>
<td>Waste, % baleᵃ</td>
<td>13.6ᵇ</td>
<td>20.6ᵇ</td>
<td>37.9ᵃ</td>
<td>3.00</td>
<td>0.03</td>
</tr>
<tr>
<td>Waste, %</td>
<td>29.3ᵇ</td>
<td>42.9ᵃᵇ</td>
<td>78.6ᵃ</td>
<td>9.53</td>
<td>0.07</td>
</tr>
<tr>
<td>DMI, % BWᵇⁿ</td>
<td>2.05</td>
<td>2.14</td>
<td>2.29</td>
<td>0.20</td>
<td>0.59</td>
</tr>
</tbody>
</table>

¹ Cone = chain cone with top and bottom sheeting, Taper = straight bottom sheeting and tapering to top, Open = no sheeting
² Largest standard error of least squared means
³ Observed significance levels for main effect of feeder
⁴ Forage waste expressed as a percentage of DM bale weight
⁵ Forage waste expressed as a percentage of calculated hay intake
⁶ Average daily forage intake expressed as a percent of calculated midpoint body weight
### Table 4.5. Corn stover sorting (Exp. 1)

<table>
<thead>
<tr>
<th>Item, % DM</th>
<th>Component</th>
<th>SEM²</th>
<th>Feeder</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bale</td>
<td>Waste</td>
<td>Orts</td>
<td></td>
</tr>
<tr>
<td>CP</td>
<td>4.49&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.20&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.62&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.36</td>
</tr>
<tr>
<td>NDF</td>
<td>77.8</td>
<td>79.0</td>
<td>79.0</td>
<td>0.90</td>
</tr>
<tr>
<td>ADF</td>
<td>48.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>50.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>49.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.88</td>
</tr>
<tr>
<td>Ash</td>
<td>9.29&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.80&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.17&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.65</td>
</tr>
</tbody>
</table>

<sup>1</sup> Component: Bale = bale core samples, Waste = waste grab samples composited by mass, Orts = orts grab samples

<sup>2</sup> Largest standard error of least squared means

<sup>3</sup> Observed significance levels for main effects of feeder and component
Table 4.6. Ammoniated corn stover sorting (Exp. 2)

<table>
<thead>
<tr>
<th>Item, % DM</th>
<th>Component</th>
<th>SEM</th>
<th>Feeder</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP</td>
<td>Bale</td>
<td>Waste</td>
<td>Orts</td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td>13.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>11.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>NDF</td>
<td>Bale</td>
<td>Waste</td>
<td>Orts</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>75.7&lt;sup&gt;c&lt;/sup&gt;</td>
<td>77.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>79.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>ADF</td>
<td>Bale</td>
<td>Waste</td>
<td>Orts</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>48.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>52.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>52.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>Bale</td>
<td>Waste</td>
<td>Orts</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>7.65&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.91&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.11&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

1 Component: Bale = bale core samples, Waste = waste grab samples composited by mass, Orts = orts grab samples
2 Largest standard error of least squared means
3 Observed significance levels for feeder and component
Figure 4.1. Round bale feeder designs used in Exp. 1 and 2: (a) open, (b) taper, and (c) cone.
Figure 4.2. Corn stover waste as a percent of bale weight by 24 h period
**Figure 4.3.** Ammoniated corn stover waste as a percent of bale weight at 24 and 48 h
LITERATURE CITED


Sexten, A. J. 2011. The Effects of Hay Processing and Feeder Design on Hay Utilization Masters, Oklahoma State University, Stillwater.


