

STRATEGIES TO IMPROVE STORED FORAGE USE EFFICIENCY

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DEXTER JAMES TOMCZAK

Dr. William J. Sexten, Thesis Supervisor

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The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled

STRATEGIES TO IMPROVED STORED FORAGE USE EFFICIENCY

Presented by Dexter James Tomczak,

a candidate for the degree of Master of Science,

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

Dr. William J. Sexten

Dr. Allison M. Meyer

Dr. Robert L. Kallenbach

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Strategies to Improve Stored Forage Use Efficiency

Dexter Tomczak

Dr. Justin Sexten, Thesis Supervisor

Abstract

Two experiments evaluated collection frequency impacts on forage waste estimates and bale diam., stocking rate, and feeder design influences on waste level. In Exp. 1, waste collection daily (**DLY**) reduced ($P < 0.05$) estimates 18% compared to collection at bale replacement (**CUML**). As waste amount increased, there was greater difference in proportion of waste that was clean between DLY and CUML estimates. Greater ($P < 0.05$) CP and Ash concentration in CUML waste than initial bale suggest increased contamination because DLY bale and waste were not different. Increased SEM for CUML waste estimates resulted in different inferences being made compared to DLY. Daily waste collection is optimal to reduce waste contamination and estimate variation. Also in Exp. 1, cone presence reduced hay waste 17%, when the same base feeder design was used. In Exp. 2, the same cone feeder was used and reduced waste 30% compared to an open ring feeder with no upper or lower section sheeting. Feeder sheeting was comparable to cone for waste reduction. In Exp. 1, bales that were 129 cm in diam. decreased ($P < 0.05$) waste compared to bale with diam. 158 cm or greater. The small bale diam. reduced waste by increasing feeding space or decreasing time to consume bale. Increased stocking rate decreased time to consume a bale, but did not change waste in Exp. 2. Waste was not influenced by time to consume bale in Exp. 2, so decreased waste in Exp. 1 was due to increased feeding space.

Chapter 1

Literature review

Introduction

Between 60 and 70% of operating costs to U.S. cow-calf producers is feed and forage (Miller et al., 2001; ERS, 2014). Winter hay feeding is common across the U.S., and is reported in Oklahoma to last 90 to 121 d (Vestal, 2007). Forage is often stored in large round bale form because it improves labor efficiency, decreases labor costs, and simplifies handling (Belyea et al., 1985). Decreasing forage losses during harvest, storage, and feeding can reduce winter feeding costs, and may be accomplished through improving efficiency at each step.

Extensive research on hay making systems suggests forage moisture level (Hoover, 1996), mower type (Rees, 1982), windrow manipulation (Savoie, 1988; Savoie and Beauregard, 1990; Buckmaster, 1993), and bale type (Koegel et al., 1985) impact DM loss. Storage loss and their influence on feeding loss has been investigated with less intensity (Atwal et al., 1984; Belyea et al., 1985). Feeding round bales in cone round bale feeders was more economical than rolling hay out, or processing into a windrow (Landblom et al., 2007). Feeder design impacts hay waste (Buskirk et al., 2003; Sexten, 2011; Moore and Sexten, 2015) with limited research on specific design features impacting hay waste. The objective of this thesis is to compare feeder design features and their influence on hay feeding waste.

Losses from standing forage to bale

Factors beyond a producer's control influencing forage yield include temperature, precipitation, and adverse weather events such as hail. Plant maturity (Robison and Massengale, 1968), cut forage respiration (Rotz and Muck, 1994), and leaf loss (Greenlees et al., 2000) impact forage nutrient concentration. Harvesting at the appropriate time, increasing drying rate, and minimizing dry forage manipulation can improve forage nutritive value. Forage nutrient concentration and maximum yield are determined during growth, but forage DM losses and nutritive value changes can be managed starting at harvest.

Shinners (2010) evaluated cutting frequency and date impacts on warm season (switchgrass) and cool season (canarygrass) plant yields. Warm season forage growth curves peak in mid-summer, while cool season forages grow rapidly during spring and autumn with reduced growth rates in mid-summer. Harvesting switchgrass once in late autumn resulted in 1-14% less DM captured compared to late summer harvest depending on the year. Three-year average yield from a single cutting was 21% less in canarygrass than switchgrass. Implementing a two cutting canarygrass system improved yield 7% over single cutting switchgrass, and 24% compared to a single cutting canarygrass (Shinners et al., 2010).

Legume plant maturity and stubble height at harvest impacts on yield were investigated by Robison and Massengale (1968). Alfalfa was harvested when 50% of plants were in the bud stage, or when 25% were in flower stage at a 2.5 cm or 10 cm stubble height 3 times each year. Within year and maturity stage there were no differences in yield due to cutting height, but harvest at more mature stage resulted in

greater yields. In year 2, forage yield was not different from year 1 when harvested at 25% flower, but was reduced when harvest occurred at 50% bud. The decline was less when plants were harvested at a 10 cm stubble height. Cutting less mature plants at lower stubble heights has a negative impact on future stand persistence and yield.

Plant maturity when harvested also impacts forage nutrient concentration. Kalu and Fick (1983) clipped different alfalfa plots to a 3 cm stubble height weekly from late May through early October for 3 years. Individual harvested shoots were classified as early, mid, or late within vegetative, bud, flower, or pod stage and analyzed for CP, NDF, and ADF. Leaf CP increased through late vegetative stage then decreased or remained unchanged while stem CP decreased as plant maturity increased. Leaf NDF (20-30%), ADF (13-22%), and lignin (3-6%) did not differ with maturity, but varied between years. Stem NDF, ADF, and lignin increased with plant maturity (Kalu and Fick, 1983). This suggests leaf nutritive value improves through late vegetation, but stem nutritive value decreases with increasing plant maturity in legumes. Increased plant maturity increases forage yields, but decreases forage nutritive value.

In addition to plant maturity and stubble height, mowing time of day can impact forage nutrient concentrations. Fisher et al. (2002) used sheep, goats, and cattle to evaluate alfalfa hay preference relative to mowing time. Evening harvested hay decreased hemicellulose, and increased IVDMD, and total nonstructural carbohydrates compared to morning harvest. All three species preferred evening cut hay, with cattle having greater differences in preference. Goats and sheep are selective grazers and have an improved ability to sort forages compared to non-selective grazers, such as cattle (Hofmann, 1988). Decreased forage sorting ability increases preference strength in relation to total plant

nutritive concentration. Increased nonstructural carbohydrate level in evening mowed hay is attributed to photosynthesis during day increasing plant simple sugar reserves, which are metabolized at night, decreasing morning mowed hay nonstructural carbohydrate levels (Fisher et al., 2002). Results suggest evening forage mowing increases palatability and preference by ruminant animals compared to morning cut hay. Forage nutritive value must be balanced with yield when determining harvest date, time and frequency.

Forage DM losses and nutrient concentration change during harvest

Dry matter losses during forage mowing are influenced by operator ability and mower type. Forage left standing in fields and around edges increase losses. Improper harvest height fails to capture maximum forage amount. Differences in mower and conditioner designs result in dry matter losses ranging from 6% to 14% (Rees, 1982). Koegel et al. (1985) compared mower-conditioner design combination influences on alfalfa DM losses. Sickle bar cutters captured 2% more DM than disk mowers, and flail conditioners lost 1.3% more than roller conditioners (Koegel et al., 1985). This suggests more intense plant processing, such as disk mowers or flail conditioners, increases DM loss especially in legumes where leaf and stem separation is more common.

Plant respiration losses are unavoidable from mowing until plant moisture is less than 40%. Existing soluble carbohydrates are used during plant respiration to produce energy, carbon dioxide, and water, decreasing non-structural carbohydrate levels. Once plant moisture is less than 40%, respiration rate slows below measurable levels (Rotz and Muck, 1994). Increased drying rate can increase soluble carbohydrate retention. Swath manipulation (tedding, swath inversion, and raking) increases forage drying rate, reducing respiration losses and rain exposure risk, but increases DM losses. Respiration

losses are expected to be 5-6% of DM, but may be up to 15% (Henning and Wheaton, 1993).

Dry matter losses from swath inversion are 1-2%, and were not different between swath inverter designs (Savoie and Beauregard, 1990). Raking losses ranged from 5-13% depending on moisture level (Buckmaster, 1993). Hoover (1996) reported a 0.26% increase in DM loss for every 1% decrease in moisture level when raking swaths. Bar rakes decreased DM losses compared to wheel rakes (Savoie, 1988; Buckmaster, 1993). Hoover (1996) reported decreased DM loss from bar rake (5.0%) compared to wheel (9.0%) and rotary (8.1%) rakes which were not different. Swath inversion and bar raking lift or roll forage, while wheel and rotary raking pull or drag forage, increasing DM losses (Hoover, 1996). Swath manipulation at greater moisture levels that lift or roll windrows reduces DM loss.

One, two, or three swaths were raked together to evaluate swath density influences on round baler losses. Increased swath density decreases baler pick-up head DM losses and bale density. Combing two or three windrows increased raking losses, which offset baling loss decreases, making total system losses not different (Anderson et al., 1981). Once forage is picked up by the baler it must then be packaged into a bale. Koegel et al. (1985) baled alfalfa hay at 18% moisture with a variable-chamber round, fixed-chamber round, and reciprocating rectangular balers. Pick-up mechanisms were not different, so only chamber loss data was collected. The fixed chamber round baler had greater losses (10.9%) than variable chamber round baler (3.8%) and reciprocating rectangular (2.8%), which were not different. Increased loss with a fixed chamber is likely due to greater loose forage tumbling during bale formation (Koegel et al., 1985).

Twine and net wrap are used to tie hay in bale form. Balers fitted with equipment to net wrap cost 15% to 25% more than twine balers, and net wrap material is \$ 0.90 to 1.20 \$/bale more expensive. Additional net wrapping expenses must be offset with increased field efficiency and decreased DM losses. Net wrapping (1.0%) decreased chamber losses compared to twine (2.9%) due to decreased bale revolutions (4 vs. 25) while tying or wrapping (Shinners et al., 2009). When hay is valued at more than 87.72 \$/909 kg, then the additional investment in net wrap is offset by DM loss reduction alone. Baling DM losses can be minimized through increased windrow density and using a variable chamber round baler with net wrap.

During hay production leaf losses are greater than stem losses, changing forage nutrient concentrations. As a proportion of DM losses, leaf losses have been reported as 75% during mowing, 54% during raking, and 80% from bale chamber (Savoie, 1982; Rotz and Abrams, 1988; Buckmaster et al., 1990). Leaves being the principle component lost during hay harvest results in increased NDF, ADF, and lignin, and decreased CP compared to the initial standing forage. Equipment used and forage moisture level from standing forage to package bale are important control points for DM loss during hay making. Increased intensity of forage manipulation increases drying rate and DM losses. Improvements in efficiency must be balanced with increases in DM losses and nutrient concentration changes.

Stored forage losses

Round bale storage strategies range from minimal capital investment with outdoor storage on soil to building permanent structures for complete weather protection. Money saved on initial investment may be lost through future DM losses. Storage location, stack

type, and weather exposure level influence storage and subsequent feeding loss. Nutrient concentration change is impacted by bale moisture level when entering storage.

Dry matter storage losses

Lechtenberg et al. (1974) first quantified storage loss differences between hay package types in mixed grass hay. Untied bales (22.3%) resulted in greater losses than twine tied (14.5%) or compressed stacks (12.6%), which did not differ. Increased losses were attributed to decreased package density (Lechtenberg et al., 1974).

Belyea et al. (1985) stored alfalfa round bales inside a barn, outside uncovered, outside covered and stacked two high with bottom row on round end, and outside covered and stacked three high with bottom row on flat end to evaluate storage and subsequent feeding losses. Storage losses were least for inside (2.5%) and greatest for outside uncovered (15.0%). Outside covered stacked two or three high were intermediate (6.2%), but not different from each other. Feeding losses were not different for bales stored inside (12.4%) or covered outside (13.4%-14.5 %), but were less than bales stored outside (24.7%). Increased weathered layer depth was measured on bales stored outside as storage time increased. The outer 20 cm represents 42% of initial bale volume in 170 cm diameter bales (Anderson et al., 1981), so round bales may cause greater losses than producers estimate. Increased losses were associated with greater bale weathering. Increasing bale protection can decrease storage losses (Atwal et al., 1984; Belyea et al., 1985; Turner et al., 2007) .

Elevating bales off the ground to reduce deterioration from ground contact was evaluated in alfalfa-orchardgrass by Baxter et al. (1986). In trial 1, round bales were stored inside, outside uncovered on automobile tires, or outside uncovered on the ground.

Losses were minimized with bales stored inside (3.3%), intermediate when stored outside on automobile tires (11.9%), and greatest in bale stored outside on the ground (16.4%). In trial 2, bales were stored inside, outside with plastic tarps, or outside uncovered. All bales in trial 2 were elevated off the ground with automobile tires. Waste was greatest when stored outside uncovered (17.9%), while inside storage (8.0%) and covered outside (5.0%) reduced waste, but were not different. Thermocouples were placed in selected bales to monitor internal temperature during curing. Forage packaged at less than 15% moisture had lower temperatures that reached equilibrium with air temperature more rapidly than forage baled at greater moisture levels. Increased curing heat increased bale ADF. Increased curing temperature with higher moisture bales not only impacts forage nutrient concentration, but can lead to bales igniting. In this research bale combustion was not reported (Baxter et al., 1986). Results from this research suggest covered and elevated from the ground outside storage can be comparable to inside storage while sparing hay barn construction expense and permanent location limitations. Baling forage with a greater moisture content increases bale temperature during curing and ADF levels, decreasing forage nutritive value.

Transportation losses for a 17.7 km distance were estimated at 0.4% of bale weight by Sanderson et al. (1997) while investigating switchgrass bale storage losses. Bale storage methods were set on grass sod or gravel or inside elevated on wood pallets. Inside storage losses (2%) were less than outside storage (5.1%), which did not differ between ground types. Lower waste estimates in switchgrass compared to previous studies may be due to lower soluble components when forage is mowed for biomass, rather than ruminant animal feed where forage nutrient concentration is also considered.

Bales stored on sod were noted to have a large rotted area where ground contact occurred (Sanderson et al., 1997). Bottom bale portion deterioration may be reduced through increased drainage below hay stacks.

Net wrap and twine tying were used by Shinnars et al. (2009) to evaluate alfalfa bale moisture and storage losses when stored for 5 or 11 months. Storage treatments included inside, covered with plastic outside, and uncovered outside on the ground or outside on pallets. Net wrap extended to or covered bale end, and twine was plastic or sisal. Net wrap reduced bale moisture compared to twine tied bales. Moisture was not different within net wrap method or twine type. Lower moisture content in net wrapped bales was associated with greater water shedding ability. Leaf losses during twine tying potentially reduce water shedding ability by creating a more penetrable outer layer made primarily of stems. Plastic covering on bales provided a moisture barrier resulting in greater moisture than net wrapped bales. Elevating bales on pallets reduced losses. Inside storage (2.0%) lost the least DM. Dry matter losses (7.4%) were not different between net wrap methods. When stored on ground, covered bale losses were not different from net wrapped bales. Sisal twine was not different from plastic twine when stored on a pallet (7.8%), but increased waste (14.6% vs. 9.9%) when stored on ground due to twine rotting and bales losing structure, causing forage loss when transporting for feeding.

Nine to 11 mo storage losses were evaluated in reed canarygrass and switchgrass. Losses were decreased using net wrap compared to twine, and by wrapping bales with plastic film or storing inside a barn, comparable to legume storage characteristics reported by Shinnars et al. (2009). Unlike legumes though, no difference was observed in bale surface moisture level between net wrapped or twine tied bales. Mature grasses with

70% NDF were harvested for this study, so large stems and fewer leaves potentially reduced water shedding ability in both bale tying types. Switchgrass was baled at greater moisture than reed canarygrass (22.5% vs. 15.2%) and had greater DM losses (4.9% vs. 1.6%), emphasizing moisture level importance to reduce microbial activity (Shinners et al., 2010). Differences in microbial activity may result in differences in forage nutrient concentrations changes during storage. Decreasing bale weather exposure through wrapping bales with plastic film or indoor storage, decreases storage DM losses. In addition to DM mass losses there are also nutrient losses that impacting nutrient concentrations.

Nutrient concentration changes during storage

Moisture level entering storage impacts retained DM quality. Rotz and Abrams (1988) square baled alfalfa at 30%, 22%, and 15% moisture and measured storage losses and nutrient concentration changes for 1 and 6 mo time periods. Increased baling moisture increased DM losses. Hay baled at 15% moisture reduced losses 41% compared to baling at 30% moisture. A slight CP increase was observed 1 mo into storage likely due to metabolism of non-structural carbohydrates, which increased CP concentrations. At 6 mo, CP levels were reduced compared to 1 mo levels. Neutral detergent fiber was increased from 44.4% to 49.6% after 6 mo in storage when bales were 25-34% moisture when entering storage, but was not different (46.5%) in 11-20% moisture hay (Rotz and Abrams, 1988). Increased microbial activity may have caused NDF concentration increases, by metabolizing nonstructural carbohydrates, and could potentially be measured as changes in bale temperature.

Following the previous study degree-days were used to measure heat generation level during storage by Rotz et al. (1991) with squared baled alfalfa at moisture greater than or less than 25%. Thermocouples were placed in bales near stack centers; temperature was recorded every 6 h for about 1 mo to calculate degree-days (days bale temperatures were greater than ambient temperature). Bales were sampled to measure DM retention and nutrient concentrations, and assigned a visual mold score (1 = no mold, 5 = heavy interior mold). Alfalfa bales at moisture less than 25% reduced degree days (20 vs. 364), mold scores (1.2 vs. 3.1) and storage loss (0.6% vs. 3.3%) compared to bales greater than 25% moisture. Forage ADF was lower in hay baled at 16% moisture (32.2%) than hay baled at 25% moisture (35.7%), but CP (17.0%) was not different after storage for 1 mo (Rotz et al., 1991). Greater degree days indicate greater microbial activity supported by decreased forage nutritive value in hay. Increased moisture level from standing forage through bale formation decreases losses due to less leaf shattering during swath formation, manipulation and baling, but may increase losses during storage because of increased microbial activity.

Forage losses during feeding

Forage feeding losses are impacted by bale feeding system, bale processing, and feeder design. Extensive research has been conducted on how feeder design affects hay waste, but research is limited on specific design features.

Feeding system losses

Lechtenberg et al. (1974) first suggested forage waste could be reduced through offering hay at maintenance needs or by limiting access to reduce stomping. Restricting

access time to a bale has been investigated as a system to reduce forage waste levels. Waste, as a percent of disappearance, reported by Cunningham et al. (2005) was not influenced by daily access time when 4 h (9.8%), 8 h (13.0%), or 24 h (18.1%) were compared. Miller et al. (2007) reported no significant differences when access time was 3 h (33.3%), 6 h (23.2%), 9 h (31.5%), or ad libitum (39.5%). Both reported reduced hay disappearance with decreased access time. Cunningham et al. (2005) used early-lactation cow-calf pairs, and reported a decrease in cow BW and BCS with decreased access time over the 60 d trial. At project conclusion cows had adequate condition ($BCS = 5.6 \pm 0.48$), and calf performance was not reduced by hay access restrictions. This is supported by Miller et al. (2007) who reported decreased disappearance in late-gestation cows during an 87 d feeding trial. An increase in BCS was reported, and likely due to decreased nutritional requirements during late-gestation compared to early lactation. Body condition score increase was greater with increased access time (Cunningham et al., 2005; Miller et al., 2007).

Moore (2013) used growing steers and heifers while limiting access time to 8 h per d or ad libitum and reported reduced ADG and forage intake with reduced access time. Intake was predicted based on BW and growth rate, and then waste was calculated as the difference between disappearance and intake. Waste was reduced 40.4% by restricting access time in an open ring feeder (Moore, 2013). Research results suggest restricting access time may impact forage waste, and can be used as a management tool for reducing forage intake.

Landblom et al. (2007) evaluated rolling hay out on the ground, processing into a windrow, or offering in a tapered-cone as a bale as winter feeding systems to evaluate

their impacts on hay waste and costs. For this study late gestation cows were fed in North Dakota during January and February over 3 yr. Initial amount of forage offered was based on NRC (1996) prediction equations and was adjusted based on changes in BCS and ultrasound fat differences at trial midpoint. Hay offered was greatest for rolling out, intermediate for processed into windrow, and least when offered in a tapered-cone feeder. Compared to tapered-cone feeder, 5.0% more hay was offered when rolling out bales, and 15.3% more when processed into a windrow. Increased hay offered was contributed to increased waste in rolling out and processing bales. This is expected because waste would be greater, due to trampling in these systems, so more hay would need to be offered for the same amount to be consumed. Processing bales into a windrow would potentially increase intake due to decreased particle size, and increase waste due to shattering. Both rolling out and processing bales could alter animal feeding behavior compared to bales offered in a round bale feeder. In the economic analysis, including hay, equipment, and labor expenses, winter costs were least for bales fed in tapered-cone (\$100), intermediate for rolling out bales (\$109), and greatest when processed into a windrow (\$127) (Landblom et al., 2007). This research suggests feeding round bales in a feeder wastes the least forage, and was the most economical.

Round bale feeder losses

Round bale feeder designs differ in shape, sheeting amount, bale position, and feeding space. Three common bale feeder types are open ring, sheeted ring, and cone. The most basic feeder design is an open ring, which has no sheeting on the perimeter of feeder. The sheeted ring has sheeting on the upper section, lower section, or both. Cone feeders suspend bales off the ground with chain or pipe cones. Hay waste and animal

behavior has been reported in different round bale feeder designs (Buskirk et al., 2003; Sexten, 2011; Martinson et al., 2012; Moore and Sexten, 2015). All previous experiments compare feeders with many design differences, but specific features' impacts on waste and behavior warrant further investigation.

Dry matter losses, and animal behavior was reported by Buskirk et al. (2003) when offered in cone, sheeted ring, trailer, and cradle feeders. Ring feeders had lower section sheeting, 18 feeding spaces separated by angled bars, and a 121 cm top rail height. Cone feeder was similar to sheeted ring feeder, but also had upper section sheeting, a cone for bale suspension, and a 191 cm top rail height. Trailer had 19 individual feeding spaces and a 163 cm top rail height. Cradle feeder had a 152 cm top rail height and no defined feeding space. Both trailer and cradle feeders were square, and had elevated bottom feeding trays. All feeders had 37 cm of linear bunk space per animal. Estimated DMI was not different between feeders and ranged from 1.8-2.0% of BW. Hay waste was greatest in cradle (14.6%), which tended to be greater than trailer (11.5%). Ring (6.1%) reduced waste compared to trailer and cradle, but was not different from cone (3.5%).

Agonistic interactions, defined as one cow displacing another from a feeder, and both regular and irregular entrance frequencies were greatest in cradle feeder. Cradle was the only feeder design that did not have individual feeding stations separated by slanted bars. Cradle feeders having the greatest waste and being the only feeder lacking these features suggests they reduce DM losses (Buskirk et al., 2003). Trailer and cradle feeders both had elevated feeding trays and increased waste compared to cone and sheeted ring. Animals prefer to consuming hay in a natural grazing position, which increases salivation

(Albright, 1993). Elevated feeding trays did not allow animals to consume hay in a natural grazing position while inside the feeder and potentially increased entrance frequency and waste. Cone feeders wasted the least hay. Lower section sheeting retained hay within feeder, similar to a feeding tray except in cone this occurred at ground level. Defined feeding space within feeder and upper portion sheeting are both features present in cone but not in ring feeders. Influences on waste by both are currently undefined and warrant further investigation.

Fifty-six crossbred beef cows were used to quantify hay waste differences between 4 round bale feeder designs. Feeders used included two open ring feeders, one open lower section steel ring (Obsr) and one open lower section polyethylene pipe ring (Poly), a steel ring with lower portion sheeting (Ring), and a modified cone feeder (Modc). Waste was lowest in Modc (5.6%), intermediate in Ring (12.7%), and greatest, but not different, between Obsr (20.7%) and Poly (21.5%). Feeder design did not impact DMI and ranged from 1.67% to 1.78% of BW (Sexten, 2011). Feeder weight is the only difference between Obsr and Poly. The lighter weight Poly could potentially be displaced more frequently by cows than the heavier Obsr, increasing waste. Waste not being different suggests feeder weight did not impact waste. Ring had individual feeding spaces separated by angled bars and lower portion sheeting, while Obsr and Poly did not. Reduced waste in Ring compared to the two open feeders agrees with Buskirk et al. (2003) who suggested individual feeding spaces reduced waste. Cone feeders in both studies reduced waste from the lower section sheeted ring by about 50 %. Sexten (2011) suggested feeding space within feeder in the Modc captures hay that would become waste in other feeders and further reduces hay waste.

Martinson et al. (2012) compared round bale feeder design impacts on orchardgrass hay waste when stocked with 5 horses. Feeders providing a greater physical barrier to hay decreased waste. Although greater physical barriers decreased waste in horses, cow DMI could potentially be limited when increased physical barriers are present because bovine prehensile organs are adapted to bulk grazing (Hofmann, 1988). Cone and lower section sheeted ring feeders were not different, similar to Buskirk et al. (2003), but individual feeding spaces did not reduce waste when offering hay to horses. Lower stocking rates were used in the horse feeding investigation than by Buskirk et al. (2003), potentially reducing agonistic interactions and hay waste. Further research is needed on feeder stocking rate in relation to number of individual feeding spaces.

Moore and Sexten (2015) used 2 forage types and 3 round bale feeder designs to investigate their influence on hay waste. High moisture alfalfa haylage (AH) and dry tall fescue hay (FH) were offered to mid-gestation crossbred cows. Open feeder had no sheeting and a 240 cm diameter. Tapered feeder had lower portion sheeting and was 240 cm in diameter at bottom and narrowed to 210 cm at the top. Cone feeder had upper and lower portion sheeting, a 230 cm diameter, and a cradle chain to elevate bale. There was a forage type by feeder interaction for hay waste. Feeder design did not influence AH waste (6.0%), but FH waste was greatest in open ring (19.2%), intermediate in tapered (13.6), and least in cone (8.9%). Bale size, density, moisture level and forage nutrient concentrations are suggested to reduce waste by the author. Moisture level differences from dry hay to balage have been reported to not influence hay waste (Comerford et al., 1994). Sexten (2011) compared forages with two particle sizes, and reported shorter particle size caused bales to deteriorate faster, and increased waste. Less dense bales may

lose structure and fall apart more rapidly similar to bales with shorter particle size, increasing waste. Decreased AH bale size compared to FH bales increased feeding space within feeder, potentially reducing waste due to animals remaining inside feeder during forage consumption. Cradle chain in cone feeder suspended bales creating a consistent sized feeding space within feeder. FH waste in cone feeder was not different from AH waste in cone or open (Moore and Sexten, 2015). Further research is needed into how feeding space within feeder influences hay waste.

There are advantages in waste reduction through feeding bales in feeders as opposed to rolling out or processing into a windrow. Feeder design influences hay waste, however specific design features warrant further research.

Dry lot cow behavior

Compared to pasture based systems, dry lots concentrate animals and feed, influencing animal to animal interactions and feed space competition. The cow-calf sector in the beef industry is traditionally a pasture based system, so limited research exists on beef cattle housed in dry lots. Dairy cows in free stall barns, and growing calves in dry lots are similar systems that have been further investigated.

Kondo and Hurnik (1990) reported greater physical agonistic interaction frequency than non-physical until a social hierarchy was established when cows not previously exposed to each other were combined into 1 group. As animals become conditioned to their rank non-physical agonistic interactions, such as threatening or avoiding, occur more frequently than physical. Social stabilization is considered established when the ratio of physical to non-physical agonistic interactions stabilizes, estimated at around 60:40, and takes 5 to 15 d (Boe, 2003). This occurs sooner when

combining groups that previously had social ranking than when all animals are foreign to each other. Middle social positions re-rank more frequently because these animals interact with higher and lower ranking animals, while animals at the top or bottom will become better conditioned by experiencing winning or losing more consistently, decreasing challenge frequency (Kondo and Hurnik, 1990).

Increased BW has been correlated to increased social rank (Guhl and Atkeson, 1959; Dickson et al., 1967; Bouissou, 1972; Olofsson, 1999), but BW has also been reported to not impact social rank (Wagnon et al., 1966). Having horns improves cow social rank and does not change if dehorned after social rank is established (Bouissou, 1972), supporting Kondo and Hurnik (1990) who suggested after social stabilization animals are conditioned to their rank.

Increasing group size is traditionally believed to increase agonistic interactions because animals are not conditioned to their rank in relation to all other individuals (Estevez et al., 2007), agreeing with Kondo et al. (1989) who reported agonistic interactions to be positively correlated with increasing group size in herds ranging from 8 to 91 cows.

Wagnon et al. (1966) compared mature Angus, Hereford, and Shorthorn cows and found Angus to be the most dominant and Shorthorn the least. Many factors including BW, horn presence, and disposition could impact breed differences and confound results. Feed was delivered to limit feeding space to 67 cm/cow in a linear bunk to evaluate feed competition. Lower ranking cows were searching for feeding space more often than higher ranking cows. Butting another cow from feeding space was most effective when targeting the shoulder or head. Cow social rank did not impact displacement frequency

once they had entered a feeding space (Wagnon et al., 1966). Konggaard (1983) supported this conclusion stating individual feeding spaces made lower ranking cows feel more protected, and less likely to be displaced from feeders.

Two common feeding systems that have been researched for cows in dry lots are total mixed rations (**TMR**) offered daily in a linear feed bunk, or hay offered ad libitum in bale feeders. Increased feed palatability increases feed competition (Metz, 1983), and increased forage quality was shown to increase DMI (Stone et al., 1960), so competition could be greater for a TMR, that contained silage for example, than low-quality forage. Differences in DM between these 2 systems potentially exist because silage is lower in DM than dry hay. Hay offered in a round bale feeder with greater DM than a TMR will allow an animal to eat less AF because bulk density is increased, potentially reducing competition for feed and feeding space. Additionally, in an ad libitum system feed is present at all times, so competition is also reduced.

DeVries et al. (2004) investigated feeding space impacts on feeding behavior in lactating dairy cows when offered a TMR in a linear feed bunk allowing 50 or 100 cm/cow. Pens providing 100 cm/cow had greater inter-cow distances than 50 cm. Animals displacements during the 90 min post-feeding were also greater at 50 cm (1.55 ± 0.17) than 100 cm (0.66 ± 0.17). Increased feeding space without individual feeding stations decreased competition for feed.

Cow to cow interaction reduction with individual feeding stations has been reported in both linear bunks (Olofsson, 1999) and in round bale feeders (Buskirk et al., 2003). Olofsson (1999) increased feeding space competition by stocking 8 cows to 2 or 8 individual feeding stations (90 cm wide) to evaluate feed competition when offered a

50:50 grass silage: concentrate diet (DM basis) ad libitum. Increased feeding station competition decreased dominance rank linearity, by middle ranking cows challenging each other more frequently, and increased cow displacement frequency similar to Zeeb et al. (1990). Social rank was most likely disrupted in middle ranking animals as suggested by Kondo and Hurnik (1990). No waste measurements were reported by Olofsson (1999).

Buskirk et al. (2003) reported increased feeder displacement frequency increased hay waste when round bales are offered ad libitum in hay feeders with no defined individual feeding spaces or 18 or 19 defined individual feeding space to pens of 20 cows. Konggaard (1983) reported decreased eating time and eating periods each day when pens were stocked to 2.9 animals per feeding station. There was no difference in DM consumed with increased stocking rate suggesting increased consumption rate. Individual feeding spaces were also suggested to prevent a dominant cow from displacing subordinate cows by limiting the area they could control. Further research is needed on feeding space competition influences on hay waste.

Animal activity is concentrated around feeders, but physical space allowed per animal also impacts animal to animal interactions. Kondo et al. (1989) reported agonistic interactions increased with decreasing space allowance to 12 m²/cow, similar to Fregonesi and Leaver (2002). Bouissou (1981) also reported increased agonistic interactions in free stall housing when animals were allocated 6 or 12 m²/cow compared to cows in a pasture with 5,500 m²/cow. Space allowance can be further decreased with completely covered dry lots or slated floor without negative impacts on performance (Zeeb et al., 1990; Fisher et al., 1997; Honeyman et al., 2012).

Housing cattle in dry lots increases animal to animal interactions, and feed competition. Sufficient feeding space and physical area are necessary to not impact animal performance.

Summary

Cow-calf producers should consider ways to reduce feed costs because they are the primary contributor to operating costs. Ideal forage harvest, storage, and feeding system may vary operation to operation. Improving forage harvest and use efficiency through the hay making process and storing hay to reduce bale weathering can increase nutrients offered to the animal. Improvements in harvest or storage strategies influence forage production costs and must be balanced with implementation costs. Offering hay in a cone round bale feeder may be ideal for operations that are concerned with hay waste. Other operations may be more cognoscente of animal health and find value in hay waste as bedding. Decisions made during hay harvest, storage, and feeding should reflect the goal to maximize profitability. Improving forage use efficiency is a potential method to maximize an operation's profit by reducing forage costs.

Chapter 2

Collection method affects hay waste estimates

Abstract

Hay waste data collection is time, labor, and equipment intensive. Decreasing collection frequency could reduce these inputs. We hypothesize decreased collection frequency would increase waste contamination, increasing estimates, without impacting DMI. Three tall fescue hay (*Festuca arundinacea* Schreb.) round bale diam. and 2 feeder designs were arranged in a 3 x 2 factorial, then randomly assigned to a 6 x 6 Latin square. Bale replacement intervals ensured ad libitum hay access. Waste was collected daily (**DLY**) or at bale replacement (**CUML**). Bales were offered on flat end in round bale feeders. A sheeted ring feeder was used with 16 chain cradle present (**SRF+C**) or removed (**SRF**). There were no differences in calculated DMI ($P > 0.54$). Greater ($P < 0.01$) waste estimates were observed for CUML than DLY as % of initial bale (20.8% vs 17.3%) and % of DMI (37.6% vs 30.0%), and average kg/d (27.7 vs 23.4). Collection frequency x feeder ($P < 0.01$) and collection frequency x bale diam. ($P < 0.02$) interactions were observed for clean and contaminated waste as % of total waste and average kg/d due to greater magnitude of difference between CUML and DLY as total waste amount increased. Greater ($P < 0.05$) CP, NDF, ADF, and ash in CUML total waste than DLY suggest greater urine, fecal, and soil contamination, contributing to increased waste estimates. Different inferences were made from CUML than DLY due to greater variance in CUML. Decreased collection frequency increased waste contamination and estimate variation.

Introduction

Previous research has quantified round bale feeder design impacts on forage waste levels (Lechtenberg et al., 1974; Buskirk et al., 2003; Moore and Sexten, 2015). Hay waste data collection including, waste sorting, transport, and weighing, and new bale offering, is time, labor, and equipment intensive. Total daily waste collection has been the most common method used (Buskirk et al., 2003; Martinson et al., 2012; Moore and Sexten, 2015), but may be increasing waste estimates by collecting forage that would be consumed. Alternatively, DiCostanzo and Jaderborg (2015) attempted to representatively sub-sample waste area and then extrapolate to entire waste area. Another reported waste collection method to reduce inputs is collection at greater than daily intervals (Martin et al., 2014). Our objective was to evaluate the effects of decreased waste collection frequency on hay waste estimates and DMI. We hypothesize decreased collection frequency would increase contamination, increasing waste estimates, and not impact DMI.

Materials and methods

Three bale diam. and 2 feeder designs were arranged in 3 x 2 factorial and assigned to a 6 x 6 Latin square with waste collection frequency as the sub-plot to evaluate collection frequency effects on hay waste estimates.

Forage

Tall fescue round bales (85.5% DM, 6.7% CP DM basis, 69.2% NDF; DM basis, 152 cm wide) were baled from alternate swaths in summer of 2013 and categorized by bale diam. as **SML** (129.1 ± 3.1 cm diam., 274.6 ± 4.1 kg), **MDM** (158.9 ± 6.2 cm diam., 445.9 ± 14.5 kg) or **LGE** (187.7 ± 3.5 cm diam., 622.4 ± 15.6 kg). Bales were stored under a roof with siding to the

north and east, and a soil floor. Bales were weighed and 3 core samples were taken per bale (Hayprobe, Hart Machine Co. Mandras, OR) no more than 3 d before offering on flat end in feeders.

Feeders

A single round bale feeder design (Hay Hopper; Action Signs and Billboards, Chandler, MN) that was 230 cm in diam., had sheeting on upper (50 cm) and lower (60 cm) sections, and was 170 cm tall with 16 individual feeding stations (41 cm wide x 69 cm tall) separated by vertical bars was used (Figure 2.1). A 16 chain cradle to suspend bales was present in the SRF+C feeder, but was removed in SRF.

Cows, supplement, and facilities

Animal use procedures were approved by the University of Missouri Animal Care and Use Committee.

At trial initiation mid-gestation cows from a spring calving herd were assigned a BCS by 2 experienced evaluators on a 1 to 9 scale as described by Wagner et al. (1988) and 2 day BW recorded. Then, 48 cows were stratified by BW (582.7 ± 77.2 kg), BCS (5.4 ± 0.6 units), and age (5.6 ± 2.5 years) into 6 replicate 18 x 61 m lots with waste lime flooring. A 9.1 x 9.1 m concrete pad was located in the center of each lot to facilitate hay feeding and waste collection. Each pen had a south-facing open-front barn (6.0 x 4.8 m), and 9.8 m of linear bunk space at north end. A dried distiller grain plus solubles based vitamin and mineral supplement containing 199 g/909 kg monenesin (Rumensin, Elanco Animal Health, Greenfield, IN) was offered at 0.91 kg DM/(cow·d).

Waste collection method

Forage on the concrete pad, not within lower section sheeting, was considered waste and was collected at 1300 h. Waste was sorted into clean and contaminated sub-groups with 5 tine pitch forks and weighed. Clean waste was dry with minimal urine or fecal contamination. Contaminated waste was visually assessed to have greater moisture level and urine or fecal contamination. Care was taken to discard manure from sub-groups, but some contamination was unavoidable. Three to 5 random grab samples were taken after weighing depending on sub-group sample size for forage component analysis.

Forage remaining in feeder (**ORT**) was removed, weighed, and sub-sampled, following the same methods as waste, before new bale offering when forage availability was estimated to limit DMI in the next 24 h. Bale replacement occurred after 2 d for SML, 3 d for MDM, and 5 d for LGE. Two replicate bales were collected each period, and averaged for statistical analysis, for SML, and 1 replicate was collected in MDM and LGE. Each period, on d 4 in SML, and d 3 MDM, another bale was offered, but not used in analysis, to provide forage until period conclusion. On d 5, all waste and ORT were collected, weighed, and sub-sampled before the next period began. Waste collection occurred over six 10-d periods. For the first 5 d waste was collected only at ORT collection (**CUML**). For the next 5 d waste was collected daily (**DLY**). Feeder and bale diam. combinations rotated through pens, while animal replicates remained in the same pen throughout experiment.

Sample analysis

Bale, waste, and ORT samples were dried in a 55° C oven for at least 72 h, ground through a 5 mm screen in a Wiley mill (Thomas Scientific; Sweedesboro, NJ), and then through

a 1 mm screen in a 1093 Cyclotec Mill (Tecator; Eden Prairie, MN) before sub-sampling. Wet chemistry analysis was used for DM (dried for 12 h at 105° C) and ash (combusted for 12 h at 500° C) determination. Crude protein, NDF, and ADF were measured with near infrared reflectance spectroscopy using the scanning, calibration, and validation methods described by Westerhaus et al. (2004). For 70 samples DM, NDF and ADF (Ankom Tech Corp; Fairport, NY), and CP (% of N x 6.25; Vario MACRO cube CN, Elementar Americas Inc; Mt. Laurel, NJ) were used to generate prediction equations. Resulting correlation coefficients were 0.94, 0.91, 0.88, and 0.90 for DM, CP, NDF, and ADF respectively.

Statistical analysis and calculations

Disappearance was calculated as the difference between bale weight and ORT. Dry matter intake was calculated as the difference between disappearance and waste. Hay waste is expressed as percent of initial bale (**%bale**), percent of intake (**%DMI**), or mass (kg/d).

Bale diam. and feeder design were arranged in a 3 x 2 factorial and assigned to a 6 x 6 Latin square. Columns represented pens, and rows represented periods. Three separate analyses were conducted for collection frequency, treatment, and composition means separation. Collection frequency analysis included collection frequency, feeder design, bale diam., and their interaction as fixed effects while pen and period were random. To test for inference consistency between collection frequencies, DLY and CUML were analyzed individually with a model including bale diam., feeder design, and their interaction as fixed effects, and pen and period as random. Component composition analysis included collection frequency, feeder design, bale diam., sample type, and their interaction as fixed effects, and period as a random effect.

Means were analyzed using MIXED procedure of SAS 9.4 (SAS Inst. Inc.; Cary, NC) with bale as the experimental unit. When treatment was significant ($P \leq 0.10$), least square means were separated using PDIFF option of SAS. Differences were declared significant at $P \leq 0.05$, and tendencies are reported when $0.05 < P \leq 0.10$.

Results and discussion

There were no collection frequency x feeder x bale diam. interactions ($P > 0.24$). As hypothesized, there were no differences ($P > 0.33$) in calculated forage DMI as %BW (1.7 ± 0.01) or kg/(hd·d) (9.9 ± 0.2) due to collection frequency, bale diam., or feeder design. No differences in calculated DMI indicate animals did not consume waste on the ground during CUML estimates, and DLY waste collection did not over estimate forage waste. There was no feeder design x collection frequency or bale diam. x collection frequency interactions ($P > 0.31$) for waste as %bale, %DMI, and kg/d. Bale diam. and feeder design main effects are further discussed in chapter 3. Total waste estimates were greater ($P \leq 0.01$) for CUML than DLY as %bale, %DMI, and kg/d. Increased waste estimates are potentially due to increased contamination levels in CUML. The proportion of total waste that was clean and nutrient concentration changes from initial bale indicate contamination level and type in waste, where changes in NDF or ADF indicate fecal contamination, and CP indicates urine contamination.

For clean and contaminated waste, there was a collection frequency x feeder (Table 2.1) and collection frequency x bale diam. (Table 2.2) interaction ($P < 0.01$) as % of total waste and average kg/d. Clean waste estimates for DLY were greater ($P < 0.05$) for SRF than SRF+C as % of total waste and average kg/d. Estimates for CUML as % of total waste were greater ($P < 0.05$) in SRF+C than SRF, but were not different ($P = 0.23$) as kg/d. As % of total waste, DLY clean waste was greater ($P < 0.05$) for LGE than MDM or SML which were not different ($P = 0.93$),

while CUMML was greater ($P < 0.05$) for SML than LGE. Proportion of clean waste in MDM was not different ($P = 0.64$) from SML, but was greater ($P < 0.01$) than LGE for CUMML. As kg/d CUMML clean waste estimates were not different ($P = 0.34$) for SML and MDM but greater ($P < 0.05$) than LGE. For clean waste, DLY MDM and LGE estimates were not different ($P = 0.93$), but greater than SML.

Both interactions for contaminated waste as % of total are the inverse of the clean waste. In kg/d, contaminated waste was greatest ($P < 0.05$) in CUMML SRF, CUMML SRF+C was intermediate ($P < 0.05$), and DLY SRF+C and DLY SRF were the least ($P < 0.05$). Contaminated waste as kg/d is greatest ($P < 0.05$) for CUMML MDM and LGE. Estimates for CUMML SML and DLY MDM and LGE were not different ($P > 0.05$), but less than ($P < 0.05$) CUMML MDM and LGE. Estimates for DLY SML were less than ($P < 0.05$) CUMML SML, but not different from DLY MDM or LGE.

Clean waste from DLY was greater ($P < 0.05$) than CUMML regardless of feeder type or bale diam. for both waste expressions. Larger bale diam. increased bale mass, decreasing bale replacement and CUMML waste collection frequency. Increasing magnitude of difference observed between DLY and CUMML with increasing bale diam., suggests increasing waste collection frequency increased clean waste, decreasing contamination. Increased contamination, from feces, urine, and forage trampling, increased CUMML waste estimates.

Crude protein in total DLY waste was not different ($P = 0.30$) compared to initial bale, while clean waste CP was less than ($P < 0.05$) initial bale (Table 2.3). Contaminated waste CP from DLY tended to increase ($P = 0.06$) from initial bale. Total and contaminated waste CP were greater than ($P < 0.05$) bale for CUMML which was greater ($P < 0.05$) than clean waste. Clean waste CP was less than ($P < 0.05$) bale for both collection frequencies. Greater ($P < 0.05$)

CP in CUML contaminated and total waste than initial bales and all CUML waste having greater CP than the corresponding DLY component, suggesting increased urine content in contaminated waste increased waste estimates for CUML. Decreased CP in total waste was reported by Buskirk et al. (2003) when offering alfalfa (*Medicago sativa*) and orchardgrass (*Dactylus glomerata*), potentially due to ability to select for greater CP containing plant portions in alfalfa hay. Moore and Sexten (2015) reported no difference between bale and total waste CP from tall fescue hay when waste was collected daily, comparable to DLY collection method in this experiment, so tall fescue hay sorting by bovines is not expected.

Total, clean, and contaminated waste had greater ($P < 0.05$), but not different ($P > 0.45$), NDF and ADF than bale for CUML. Total, clean, and contaminated waste NDF and /ADF from DLY were also greater ($P < 0.05$) than bale. Clean DLY NDF and ADF were greater ($P < 0.05$) than contaminated, and total NDF and ADF was intermediate, but not different ($P > 0.07$). Waste from CUML had a greater magnitude of increase than DLY from initial bale for NDF and ADF suggesting decreased ability to sort feces from waste due to trampling or cows bedding on accumulated waste around feeders.

Initial bale ash was not different ($P > 0.13$) in clean, contaminated, or total waste ash for DLY. Contaminated and total waste ash were greater ($P < 0.05$) than bale and clean waste in CUML. Greater waste ash content compared to bale indicates soil and fecal contamination. A greater magnitude of difference between initial bale and waste was observed for CUML compared to DLY indicating greater contamination than DLY.

When evaluating feeder designs or estimating bale waste differences, increased estimates are tolerable if magnitude of differences and variation between estimates are not different and similar inferences are made. To test this, collection frequency estimates were analyzed as

separate data sets and results compared. Significance level and SEM for collection frequencies are presented in 2.4. The bale size x feeder design interaction was not significant ($P > 0.51$) for either collection method regardless of waste expression. Bale diam. influenced hay waste ($P < 0.01$) as %bale, %DMI, and kg/d for DLY. Bale diam. did not influence waste as %bale ($P = 0.12$), %DMI ($P = 0.30$), but did change ($P < 0.01$) waste as kg/d for CUMML. Feeder designs tended to influence waste as %DMI ($P = 0.09$) for DLY, but was not significant ($P > 0.15$) for CUMML. Cumulative estimate SEM's were 2 to 3 fold greater than DLY. As stated previously, waste estimates are greater in CUMML than DLY, but this increase does not explain all SEM differences. Similar replicates ($n = 48$) were collected for each frequency, so increased SEM must be due to greater waste estimate variation. Increased variability in CUMML waste estimates influenced conclusions, by bale diam. not being significant as %bale ($P = 0.12$) or %DMI ($P = 0.30$), while it bale diam. was significant for DLY ($P < 0.01$).

Implications

Daily waste collection decreased waste estimates and variation without impacting DMI. Increased fecal and urine contamination occurs when waste is allowed to accumulate as indicated by less clean waste, and greater CP, NDF, ADF, and ash in CUMML waste. Increased variation in waste estimates for CUMML changed experimental conclusions. Daily waste collection was optimal to increase waste estimate repeatability.

Table 2.1. Collection frequency and feeder design effects on DMI and waste type

Item	Collection frequency ²				SEM ⁴	P-value ¹		
	CUML		DLY			Feeder design	Collection frequency	Feeder x Collection Frequency
	SRF+C ³	SRF	SRF+C	SRF				
DMI⁵								
kg/(cow·d)	9.9	9.7	10.1	9.8	0.3	0.46	0.54	0.94
%BW	1.69	1.66	1.72	1.68	0.05	0.46	0.54	0.95
Waste								
Total								
%bale ⁶	19.0	22.7	16.4	18.3	1.2	0.03	<0.01	0.48
%DMI ⁷	34.7	40.5	28.0	32.0	3.1	0.12	0.01	0.75
kg/d	24.4	29.2	22.2	24.7	1.6	0.03	<0.01	0.45
Clean								
%of waste ⁸	22.4 ^c	12.8 ^d	37.4 ^b	45.2 ^a	3.1	0.76	<0.01	<0.01
kg/d	4.4 ^c	3.2 ^c	8.3 ^b	11.2 ^a	0.7	0.30	<0.01	<0.01
Contaminated								
%of waste	77.6 ^b	87.2 ^a	62.6 ^c	54.8 ^c	3.1	0.76	<0.01	0.01
kg/d	19.9 ^b	26.6 ^a	13.7 ^c	13.5 ^c	1.4	0.03	<0.01	0.01

^{a-d}Within a row means without common superscript differ (P < 0.05)

¹Observed significance level for feeder design, collection frequency, and 2-way interaction

²CUML = waste collected at new bale offering, DLY = waste collected every 24 h

³Feeder with sheeted upper and lower section, and individual feeding stations (Hay Hopper; Action Signs and Billboards, Chandler, MN) SRF+C = with cradle chain, SRF = removed cradle chain

⁴Largest standard error of least squared means

⁵Calculated DMI = initial bale – (waste + ORT), DMI expressed as kg/(cow·d) and % of BW

⁶Forage waste expressed as percentage of initial bale DM

⁷Forage waste expressed percentage of calculated DMI

⁸Type of waste as percentage of total waste

Table 2.2. Collection frequency and bale diameter effects on DMI and waste type

Item	Collection frequency ²						SEM ⁴	P-value ¹		
	CUML			DLY				Bale diam.	Collection Frequency	Collection Frequency x Bale diam.
	SML ³	MDM	LGE	SML	MDM	LGE				
DMI ⁵										
kg/(cow·d)	9.7	9.4	10.2	10.1	10.0	9.8	0.4	0.76	0.54	0.33
%BW	1.67	1.60	1.75	1.73	1.71	1.67	0.08	0.76	0.54	0.34
Waste										
Total										
%bale ⁶	17.7	22.9	22.0	14.2	18.0	19.8	1.7	<0.01	<0.01	0.71
%DMI ⁷	32.9	44.3	35.6	24.8	33.6	31.6	4.2	0.03	0.01	0.70
kg/d	20.0	32.2	28.0	19.6	26.3	24.4	2.1	<0.01	<0.01	0.31
Clean										
%of waste ⁸	23.0 ^c	20.5 ^{cd}	9.1 ^d	39.3 ^b	39.7 ^b	44.9 ^a	4.2	0.48	<0.01	0.02
kg/d	4.2 ^c	5.3 ^{bc}	1.9 ^d	7.9 ^b	10.7 ^a	10.6 ^a	1.0	0.08	<0.01	0.01
Contaminated										
%of waste	77.0 ^b	79.5 ^b	90.8 ^a	60.7 ^c	60.3 ^c	55.1 ^d	4.2	0.48	<0.01	0.02
kg/d	17.5 ^b	26.9 ^a	25.3 ^a	11.7 ^c	15.3 ^{bc}	13.7 ^{bc}	1.9	<0.01	<0.01	0.08

^{a-d}Within a row means without common superscript differ ($P < 0.05$)

¹Observed significance level for bale diam., collection frequency and 2-way interaction

²CUML = waste collected at new bale offering, DLY = waste collected every 24 h

³SML = 129 cm diameter, MDM = 158 cm diameter, LGE = 188 cm diameter

⁴Largest standard error of least squared means

⁵Calculated DMI = initial bale – (waste + ORT), DMI expressed as kg/(cow·d) and % of BW

⁶Forage waste expressed as percentage of initial bale DM

⁷Forage waste expressed percentage of calculated DMI

⁸Type of waste as percentage of total waste

Table 2.3. Collection frequency effects on waste component nutrient concentration in relation to initial bale

Item,%	Collection frequency ¹								SEM ⁴	P-value ²		
	CUML				DLY					Collection frequency	Component	Collection frequency x component
	Bale ³	Waste			Bale	Waste						
Total	Clean	Contaminated	Total	Clean	Contaminated	Collection frequency	Component	Collection frequency x component				
CP	6.7 ^{bc}	7.1 ^a	6.5 ^d	7.2 ^a	6.6 ^{bcd}	6.5 ^{cd}	6.2 ^e	6.8 ^b	0.08	<0.01	<0.01	0.01
NDF	69.6 ^{de}	73.8 ^a	73.4 ^a	73.7 ^a	69.2 ^e	71.3 ^{bc}	71.7 ^b	70.3 ^{cd}	0.46	<0.01	<0.01	<0.01
ADF	40.5 ^d	44.2 ^a	44.0 ^a	44.0 ^a	40.2 ^d	42.4 ^{bc}	42.8 ^b	41.7 ^c	0.30	<0.01	<0.01	<0.01
Ash	9.1 ^{ab}	11.6 ^c	9.6 ^{ab}	12.1 ^c	9.8 ^{ab}	9.7 ^{ab}	8.8 ^a	10.4 ^{bc}	0.55	0.01	<0.01	0.03

^{a-e}Within a row means without common superscript differ ($P < 0.05$)

¹CUML = waste collected at new bale offering, DLY = waste collected every 24 h

²Collection frequency, component and collection frequency x component interaction significance level

³Bale = bale core samples, Total = total waste composited by mass, Clean = waste free from fecal and urine contamination, Contaminated = waste potentially containing fecal and urine contamination

⁴Largest standard error of least squared means

Table 2.4. Collection frequency influences on main effect significance level, mean, and SEM for waste estimates

	<i>P</i> -value ¹		Mean ²		SEM ³	
	CUML ⁴	DLY ⁵	CUML	DLY	CUML	DLY
Bale diam.						
kg/d	<0.01	<0.01	58.9	51.6	6.12	3.09
%bale ⁶	0.12	<0.01	21.0	17.0	2.28	1.20
%DMI ⁷	0.30	<0.01	38.0	29.7	6.18	2.24
Feeder						
kg/d	0.11	0.14	59.4	55.5	4.56	2.45
%bale	0.15	0.11	21.0	19.1	1.67	0.93
%DMI	0.38	0.09	38.0	33.4	4.51	1.65

¹Observed significance level for bale diam. and feeder

²Arithmetic mean for main effect within parameter

³Largest standard error of least squared means

⁴CUML = waste collected at new bale offering

⁵DLY = waste collected every 24 h

⁶Forage waste expressed as percentage of initial bale DM

⁷Forage waste expressed percentage of calculated DMI

Figure 2.1. Round bale feeder designs: Sheeted upper and lower sections and vertical bars separating 16 individual feeding spaces (a) with cradle chain (SRF+C), or (b) without cradle chain (SRF) (Hay Hopper; Actions Signs and Billboards, Chandler, MN).



(a)



(b)

Figure 2.1

Chapter 3

Bale diameter, stocking rate, and feeder design affects hay waste and intake in beef cattle

Abstract

Two experiments were conducted to evaluate bale diam., stocking rate (**SR**), and feeder design influences on hay waste and DMI. In Exp. 1, 48 mid-gestation cows were stratified by BW, BCS, and age into 6 pens. Tall fescue round hay bales (85.5% DM, 6.7% CP, 69.2% NDF, 152 cm wide) were classified by diam. as **SML** (128.3 ± 3.19 cm), **MDM** (160.7 ± 6.38 cm), or **LGE** (187.7 ± 3.52 cm). A sheeted ring feeder (230 cm diam., 170 cm height, 50 cm upper and 60 cm lower section sheeting, 16 feeding stations separated by vertical bars) was used with cradle chain present (**SRF+C**) or without (**SRF**). We hypothesized hay waste would increase as initial bale diam. increased in SRF due to decreased feeding space, but feeding space and waste would not differ in SRF+C. In Exp. 2, 96 mid-gestation cows were stratified by BW, BCS, and age into 6 replicate groups of 8, 16, or 24 cows to evaluate SR and feeder design effects on hay waste. An open round bale feeder (**OPN**) with no sheeting (240 cm diam., 120 cm height), and 17 feeding stations separated by angled bars and SRF+C were used in Exp. 2. Bales were offered on end and bale replacement rate ensured ad libitum access. In Exp. 1, Bale diam. and feeder design were the main effects, while SR and feeder design were in Exp. 2. Main effects were arranged in a 3 x 2 factorial in each experiment and randomly assigned to a 6 x 6 Latin square. Waste was collected daily, and residual forage (**ORT**) was

removed before new bale offering. Calculated DMI was not different due to bale diam. ($P > 0.68$), SR ($P > 0.81$), or feeder ($P > 0.21$). In Exp. 1, waste was reduced ($P < 0.05$) in SML compared to MDM and LGE, which were not different ($P > 0.10$). Waste was reduced ($P = 0.09$) by SRF+C compared to SRF. Time to consume bale differed due to bale diam., so data were analyzed as an incomplete Latin square to evaluate feeder effects over time. Waste was not different ($P > 0.10$) between d in SML or MDM SRF+C, however waste was reduced ($P < 0.05$) with increased d of exposure in LGE SRF+C and all bale diam. in SRF. In Exp. 2, a SR by feeder interaction was observed due to changes in magnitude of difference between SRF+C and OPN when waste was expressed as kg/(cow·d) ($P = 0.05$), and percent of DMI ($P = 0.10$). Open ring feeder waste was greater ($P < 0.05$) than SRF+C for 8 and 24, and increased ($P < 0.09$) for 16. Upper and lower section sheeting and SML bales reduced forage waste, while stocking feeders at greater than 1 cow per defined feeding space did not influence forage waste.

Introduction

Feed and forage constitutes 60-70% of operating expenses to U.S. cow-calf producers (Miller et al., 2001; ERS, 2014). Hay price volatility due to production fluctuations makes future feed budgeting a challenge. Reducing hay feeding waste can decrease feed costs. Landblom et al. (2007) reported offering round bales in a feeder reduced hay waste and wintering costs for cows compared to rolling out or processing into a windrow. Previous research has compared feeder design influences on hay waste (Lechtenberg et al., 1974; Buskirk et al., 2003; Sexten, 2011), but research on specific features within these designs is limited.

Moore and Sexten (2015) compared alfalfa haylage (**AH**) and dry tall fescue hay (**FH**) offered in an open ring, tapered ring with lower section sheeting, and cone feeders to mid-gestation cows. Alfalfa haylage waste did not differ between feeders and cone reduced FH waste. Bale size, bale density, forage moisture content, and forage nutrient concentration were suggested as factors contributing to AH waste reduction by the authors. Decreased AH bale size compared to FH bales increased feeding space within feeder and decreased DM mass per bale, potentially reducing waste due to animals remaining inside feeder during meals or by decreasing time to consume a bale.

Therefore, objectives of this study were to evaluate increasing feeding space within feeder by decreasing bale diam. and decreasing time for bale consumption by increasing feeder stocking rate (**SR**) influences on hay waste. In Exp. 1, bale diam. was different causing differences in feeding space and time to consume a bale. We hypothesized waste would decrease with decreasing bale diam. in a sheeted ring feeder, and not differ in cone due to feeding space being standardized by cone feeder but not in sheeted ring. In Exp. 2, bale diam. was not different, but SR was increased which changed time to consume a bale. We hypothesized waste would decrease with increasing SR independent of feeder type.

Materials and methods

Animal use procedures were approved by the University of Missouri Animal Care and Use Committee.

Experiment 1

Forty-eight mid-gestation crossbred beef cows from a spring calving herd were stratified by BW (582.7 ± 77.2 kg, SD), BCS (5.4 ± 0.6 units, SD), and age (5.6 ± 2.5 years, SD) into 6 replicate pens to evaluate bale diam. and feeder design influences on hay waste and DMI. Three bale diam. and 2 feeder designs were arranged in a 3 x 2 factorial design and randomly assigned to a 6 x 6 Latin square. Animal replicates remained in the same pen throughout experiment, while bale diam. x feeder design combinations rotated through pens. A sheeted (50 cm upper, 60 cm lower) round bale feeder (230 cm diam., 170 cm height; Hay Hopper; Action Signs and Billboards, Chandler, MN) with 16 individual feeding stations (41 cm width x 69 cm height) separated by vertical bars was used. A 16 chain cradle to suspend bale remained in cone feeder (**SRF+C**), and was removed in the sheeted ring feeder (**SRF**, Figure 3.). In SRF+C, the cradle chain suspended bale potentially reducing variation in feeding space between bale sizes, while in SRF feeding space was only influenced by bale diam. Tall fescue hay (85.5% DM, 6.7% CP, 69.2% NDF, 40.2% ADF, 9.2% Ash) was baled from alternate swaths in summer of 2013 in 3 diameters. Bales (152 cm wide) were classified by diam. as **SML** (129.1 ± 3.1 cm diam., 274.6 ± 4.1 kg), **MDM** (158.9 ± 6.2 cm diam., 445.9 ± 14.5 kg), or **LGE** (187.7 ± 3.5 cm diam., 622.4 ± 15.6 kg) and stored in a dirt floored barn with siding to the North and East. Bales were weighed and 3 core samples taken (Hayprobe, Hart Machine Co. Mandras, OR) no more than 3 d before offering on flat end in feeders. The experiment was 60 d long with six 10-d periods. Cows were allowed 5 d for acclimation to feeder x bale diam. combination before waste collection began. Bale replacement occurred after 2 d for SML, 3 d for MDM, and 5 d for LGE to

ensure ad libitum forage access. During each period, 2 replicate bales were collected for SML, and 1 replicate was collected for MDM and LGE. On d 4 in SML, and d 3 MDM, a new bale was offered to provide forage until period conclusion. On d 5, all waste was collected and residual forage removed before the next period started.

Experiment 2

Ninety-six mid-gestation crossbred beef cows were stratified from 2 spring calving herds by initial herd, BW (562.9 ± 72.6 kg), BCS (4.9 ± 0.7 units), and age (4.5 ± 2.0 yr) into 6 replicate groups of 8 (**SR-8**), 16 (**SR-16**), or 24 (**SR-24**) cows. The 2 feeders used were an open-ring feeder (**OPN**) 240 cm in diam. and 120 cm tall with no upper or lower section sheeting and 17 feeding stations (44.4 cm wide) separated by angled bars and SRF+C from Exp. 1. The 3 stocking rates and 2 feeder designs were arranged in a 3 x 2 factorial and randomly assigned to a 6 x 6 Latin square. Cows were given 10 d for social hierarchy stabilization (Boe, 2003) with 5 d exposure to each feeder before waste collection began. There was no additional feeder acclimation once waste collection began. Tall fescue round bales (87.3% DM, 6.33% CP, 64.0% NDF, 40.6% ADF, 10.9% Ash, 152 cm width x 170 cm diam.) from a single harvest in summer 2014 were offered on flat end in round bale feeders. During social acclimation, new bales were offered when forage remaining in feeder (**ORT**) was visually estimated to become limiting in the next 24 hours. By design bale replacement did not occur at the same time for each SR, increased SR increased bale replacement frequency. To ensure ad libitum forage access, bale replacement and ORT collection during waste collection occurred every third d (SR-8), every other d (SR-16), or daily (SR-24) during 3 d collection periods. At collection period conclusion, all ORT were collected and new bales offered.

Bale sampling was the same as Exp. 1. Each period throughout the experiment, SR groups were exposed to alternate feeder designs.

Cow measures, facilities, and supplementation

In Exp. 1 and 2, at trial initiation and conclusion BCS were assigned and 2-day BW measured. The same 2 experienced evaluators assigned BCS on a 1 to 9 (Wagner et al., 1988). Animals were housed in 18 x 61 m lots with waste lime flooring and a south-facing open-front barn (6.0 x 4.8 m). There was 9.8 m of linear bunk space at north end. Animals were housed in the same facilities for Exp. 1 and 2. During Exp. 2, a 3.1 m portable feed bunk (Heavy-Duty Bunk Feeder, Tarter Farm & Ranch, Dunnville, KY) was placed in both SR-24 pens to allow at least 51 cm/cow of bunk space. Supplement containing 199 g/909 kg monenesin (Rumensin, Elanco Animal Health, Greenfield, IN) was offered at 0.91 kg DM/(cow·d) during Exp. 1 and 2 (Table 3.1).

Waste collection method

A 9.1 x 9.1 m concrete pad was located in center of the pen for hay offering and waste collection. Forage on concrete pad, not within feeder, was considered waste and was collected daily at 1300 h. Waste was sorted into clean and contaminated sub-groups with 5 tine pitch forks and weighed. Clean waste was dry with minimal urine or fecal contamination. Contaminated waste was visually assessed to have greater moisture level, and urine or fecal contamination. Care was taken to discard manure from sub-groups, but some contamination was unavoidable. Three to 5 random grab samples were taken after weighing, depending on sub-group sample size, for forage component analysis.

Forage remaining in feeder when forage availability was estimated to become limiting in the next 24 h was considered ORT (Moore and Sexten, 2015) and was weighed and sub-sampled following the same methods as waste before new bale offering. The same collection methods were used in Exp. 1 and 2.

Sample analysis

All forage samples from Exp. 1 and 2 were dried in 55° C oven for at least 72 h, ground through a 5 mm screen in a Wiley mill (Thomas Scientific; Sweedesboro, NJ), and then through a 1 mm screen in a 1093 Cyclotec Mill (Tecator; Eden Prairie, MN), before sub-sampling. For all waste and ORT samples wet chemistry analysis was used for DM (dried for 12 h at 105° C), and ash (combusted for 12 h at 500° C) determination.

In Exp. 1, NDF, ADF, and CP was measured in all samples with near infrared reflectance spectroscopy using the scanning, calibration, and validation methods described by Westerhaus et al. (2004). For 70 validation samples, DM, NDF, and ADF (Ankom Tech Corp; Fairport, NY), and CP (% of N x 6.25; Vario MACRO cube CN, Elementar Americas Inc; Mt. Laurel, NJ), were used to generate prediction equations. Resulting correlation coefficients were 0.94, 0.91, 0.88, and 0.90 for DM, CP, NDF and ADF respectively. These predictions were used for initial bale forage nutrient concentration. In Exp. 2, initial forage nutrient concentration was determined using the same wet chemistry analysis as the validation samples in Exp. 1.

Statistical analysis and calculations

Disappearance was calculated as the difference between initial bale weight and ORT. Dry matter intake was calculated to be the difference between disappearance and waste. Hay waste is expressed as percent of initial bale (**%bale**), percent of intake (**%DMI**), or average mass per cow per day (kg/(cow·d)).

Because multiple replicates of SML in Exp. 1 and SR-24 in Exp. 2 were collected, estimates were averaged within period for statistical analysis. Separate models were used for treatment and waste over time analysis. The treatment model in Exp. 1 included bale diam. and feeder design main effects and their interaction as fixed effects, while Exp. 2 included SR and feeder design main effects and their interactions. Pen and period were included in both models as random effects. In Exp. 1, bale time on offer differed due to bale diam., so data were analyzed as an incomplete 6 x 6 Latin square to evaluate feeder effects on waste relative to time since bale offering for each bale diam. individually. The model for waste over time by bale diam. included feeder design, day, and the interaction as fixed effects, and period as a random effect. Means were analyzed using MIXED procedure of SAS 9.4 (SAS Inst. Inc.; Cary, NC) with bale as the experimental unit in Exp. 1 and 2. Least square means were separated using PDIFF option of SAS when fixed effect $P \leq 0.10$. Differences were significant at $P \leq 0.05$, tendencies are discussed when $P \leq 0.10$.

Results and discussion

Experiment 1

Calculated forage DMI was not influenced by feeder design (Table 3. 2) or bale diam. (Table 3. 3) as %BW ($P > 0.45$) or kg/(cow·d) ($P > 0.45$), and was similar to forage intake reported by Sexten (2011) who also use non-lactating cows. Bale suspension and retention in feeder center by SRF+C did not limit cows' ability to access forage. There was no difference in ORT between MDM and LGE, but both were greater ($P < 0.05$) than SML. Contrary to our hypothesis, there were no feeder design x bale diam. interactions, potentially due to greater variation in feeding space with flexible cone than expected. Cradle chain flexibility in SRF+C may have allowed greater change in feeding space with bale diam. than hypothesized due to cone changing shape to form around the bale. Because no feeder design x bale diam. interactions were significant, only main effects will be presented.

Hay waste tended to be reduced ($P = 0.09$) in SRF+C compared to SRF as %DMI, but was not different ($P > 0.10$) as %bale or kg/(cow·d). In this experiment feeders were the same basic design, differing only by cradle chain presence. Previous research suggests cone feeders reduce waste 42-55% compared to ring feeders (Buskirk et al., 2003; Sexten, 2011; Moore and Sexten, 2015), but these used cone feeders with upper and lower section sheeting compared to ring feeders without upper section sheeting. The lack of upper section sheeting allows cows access to forage above the feeder. Buskirk et al. (2003) reported a positive correlation between entries above top rail and hay waste. The 10-14% waste reduction by SRF+C compared to SRF was less than previous

research and may be due to sheeting on upper and lower sections reducing irregular feeder entries. A challenge with cone feeder designs is the increased need for equipment to place bale into cone. In feeders without a cone, bale can be placed on the ground and feeders then placed around the bale. Upper and lower section sheeting may be an effective alternative for cone type feeders.

When waste was expressed as kg/bale, LGE is the greatest ($P < 0.05$), MDM is intermediate ($P < 0.05$), and SML is the least ($P < 0.05$) due to differences in days to consume a bale. When differences in days to consume a bale were corrected for, waste was less ($P < 0.04$) in SML than MDM and LGE, which were not different ($P > 0.10$) when expressed as kg/(cow·d), %bale, and %DMI. In SRF+C, no differences in feeding space in relation to bale diam. were expected due to cradle chain standardizing feeding space. Feeding space was not measured, but is expected to increase as bale diam. decreased in SRF and bale exposure time increased. In SRF, feeding space is calculated as space from initial bale diam. to feeder perimeter. There were no differences in waste when feeding space within SRF at bale offering was 31 to 21 cm, but when feeding space increased to 51 cm waste was reduced. Konggaard (1983) suggested individual feeding spaces make animals feel more protected and less likely to be displaced from feeders. Buskirk et al. (2003) reported decreased cow displacements from feeder and decreased feeder entrance frequency decrease waste. Feeder entrances may have been reduced by SML by allowing animals to consume hay in the preferred natural grazing position (Albright, 1993) inside the feeder where they felt more protected.

Because the 3 bale diam. were offered for a different number of days, each bale diam. was analyzed separately. Over time, day x feeder interactions were observed for

SML ($P < 0.001$), MDM ($P = 0.08$), and LGE ($P = 0.09$). Waste from SML (Figure 3.) was greater ($P < 0.05$) at d 1 in SRF (36.4%) than SRF+C (21.3%), but SRF+C was greater ($P < 0.05$) at d 2 (25.0%) than SRF (17.0%). In SRF, d1 was greater ($P < 0.05$) than d 2, but in SRF+C was not different ($P > 0.10$) between d 1 and d 2. For MDM (Figure 3.), waste was increased ($P = 0.09$) at d 1 in SRF, but did not differ ($P > 0.35$) between feeder on d 2 or 3. Waste in MDM did not change ($P > 0.62$) over time in SRF+C (29.4%), but tended to decrease from d 1 (50.3%) to d 2 (37.1%) ($P = 0.10$), and from d 2 to d 3 (22.3%) ($P = 0.07$) and waste was reduced ($P < 0.01$) at d 3 compared to d 1 in SRF. For LGE (Figure 3.), waste did not differ ($P > 0.18$) within d between feeders except d 3 when SRF was greater ($P = 0.02$) than SRF+C. In SRF d 1 (44.6%), d 2 (42.1%), and d 3 (38.1%) waste were not different ($P > 0.31$), but were greater ($P < 0.05$) than d 4 (25.2%). Waste at d 5 (14.7%) tended to be reduced ($P = 0.10$) compared to d 4 in SRF. Waste was greatest ($P = 0.05$) in LGE SRF+C at d 1 (49.3%). At d 2 (36.6%) waste was less ($P = 0.05$) than d 1, but greater ($P < 0.001$) than d 3 (23.2%) which was not different ($P > 0.87$) from d 4 (24.2%), or 5 (23.8%) in SRF+C.

Moore and Sexten (2015) defined feeding space as area allowed for feeding inside the feeder and to be measured as space between newly offered bale and feeder. As d since bale offering increased, waste decreased in SRF regardless of bale diam. Feeding space is expected to increase as a bale is consumed, supporting suggestions by Moore and Sexten (2015) that waste decreases with increased feeding space. In SRF+C, cradle chain flexibility potentially allowed reduced feeding space in LGE due to bale displacing chains to feeder perimeter. At d 2 chains may have returned to similar position as SML and MDM which is supported by waste not differing in SML and MDM, or at d 2 through

d 5 in LGE. This is in contrast to Moore and Sexten (2015) who reported feeding space in cone to be feeder diameter when bale diam. was 110 or 150 cm due to bale being suspended. Similar waste patterns were observed for SML and MDM waste, and the last 3 d of LGE bale offering suggesting forage waste is influenced by feeding space as modeled by decreasing forage available in feeder.

Similar to Exp. 1, Moore and Sexten (2015) used SRF+C with 8 animals per pen. Their tall fescue hay bales were between MDM and LGE for mass, but between SML and MDM for bale diam., indicating denser bales. Additionally, their tall fescue hay had decreased NDF and ADF and increased CP compared to Exp. 1 forage. Waste ranged from 25.0% DMI for SML to 33.0% DMI for MDM, 2 to 2.7 times greater than Moore and Sexten (2015). Increased waste may be due to decreased bale density or poorer quality forage.

A limitation of Exp. 1 is time to consume a bale and bale diam. effects were inseparable. Restricting access time during the day has been reported to not influence hay waste (Cunningham et al., 2005; Miller et al., 2007) or to reduce waste (Moore, 2013). Previous research investigated access time each day, and was not in relation to time for bale consumption. Increasing SR can be used to model change time for bale consumption without changing bale diam.

Experiment 2

Calculated forage DMI was not influenced ($P > 0.21$) by feeder or SR (Table 3.4), and is comparable to previous reports (Buskirk et al., 2003; Moore and Sexten, 2015). Increasing SR to greater than one cow per defined feeding space increased feed space

competition. Konggaard (1983) stocked 60 cows to 21 feeding spaces and 57 cows to 55 feeding spaces and reported increased feeding space competition increased feed consumption rate, but did not change DMI. Although behavioral data was not collected in the present study, increased eating rate is expected because calculated DMI was not different across treatments.

Initial bale weight was not different due to treatment ($P > 0.46$). Greatest ($P < 0.05$) ORT were in SR-24, SR-8 was intermediate, and SR-16 was least. Waste was greater ($P < 0.05$) when expressed as %bale and kg/bale in SR-16, than SR-8 or 24 which were not different ($P > 0.80$). Differences in ORT potentially caused differences in waste as %bale and kg/bale because as ORT decreases, disappearance increases. Increased disappearance (waste + DMI) increased hay potentially wasted. Expressing waste as %bale or kg/bale in present experiment may bias comparisons due to differences in disappearance. Calculated DMI was not different across treatments, so waste expressed as %DMI reduces potential bias. Feeder did not influence ORT ($P = 0.21$), but waste was greater ($P < 0.05$) in OPN than SRF+C for all waste expressions. In SRF+C, cradle chain increased feeding space by suspending bales and upper and lower section sheeting potentially reduced irregular feeder entries reducing waste in SRF+C as described by Buskirk et al. (2003). There was a SR x feeder interaction for waste as kg/ (cow·d) ($P = 0.05$), which tended to be significant ($P = 0.10$) when expressed as %DMI. Waste did not differ with SR ($P > 0.63$). The interaction occurred due to changes in magnitude of difference between feeders where OPN was greater ($P < 0.05$) than SRF+C at SR-8 and SR-24, and OPN compared to SRF+C tended to increase waste at SR-16 as %DMI ($P = 0.10$) and kg/ (cow·d) ($P = 0.05$). Waste as %DMI and kg/(cow·d) are the only

comparable measures between the 3 SR. The main effects of time to consume a bale and SR were nested, waste did not differ ($P > 0.63$) between SR regardless of feeder design. Waste was not influenced by time to consume a bale or SR.

Overall

In Exp. 1, SML reduced waste due to increased feeding space or reduced time to consume a bale. Waste being reduced over time in SRF suggests increasing feeding space, from decreased forage present in feeder, decreased waste. Feeding space was not different at bale offering in Exp. 2, but bale consumption time was reduced by increasing SR to each feeder, and waste was not different. Decreased waste with decreasing bale diam. in Exp. 1 is likely due to increased feeding space.

When a single feeder design was used differing only by cradle chain cone presence, SRF+C numerically reduced waste compared to SRF by 13-21%. Waste was reduced 29-31% by SRF+C compared to OPN in Exp. 2. Greater differences in waste between SRF+C and OPN than SRF+C and SRF suggest waste reducing ability of feeder sheeting on upper and lower section as a comparable alternative for cone feeder designs.

Implications

Increased feeding space within a feeder reduced hay waste. Two potential ways feeding space can be increased are increasing feeder size or decreasing bale diam. Smaller bales will increase bale numbers for the same amount of forage harvested, potentially decreasing forage packaging efficiency and increasing baling and storage waste. Increasing feeder diam. to reduce feeding waste will be limited by how far the

animal can reach into the feeder. Increased SR to greater than 1 cow per individual feeding station did not influence forage waste. Total feeder cost may be reduced by increasing stocking rate to each feeder.

Table 3.1. Supplement composition DM basis

Item, %DM	Experiment	
	1	2
Dried distillers grains + solubles	84.8	87.1
Mineral premix		
Exp. 1 ¹	15.2	-
Exp. 2 ²	-	12.9
Monensin, g/909 kg	199	199
DM	88.6	89.0
CP	26.6	24.4
NDF	25.2	27.8
ADF	7.7	8.1
Ash	19.3	14.8

¹Mineral premix experiment 1 = 12.4% NaCl, 45.4% CaCO₃, 6.7% MgO, 8.4% trace mineral premix (Zn 3.0%, Fe 2.5%, Mn 2.0%, Cu 1.0% , 100 ppm Co, 500 ppm I 100 ppm Se), 7.9% vitamin premix (8,800,000 IU/kg vitamin A, 1,760,000 IU/kg vitamin D, 1,100 IU/kg vitamin E), 19.2% vitamin E premix (44,000 IU/kg)

²Mineral premix experiment 2 = 22.0% NaCl, 42.3% CaCO₃, 6.5% MgO, 8.1% trace mineral premix (Zn 3.0%, Fe 2.5%, Mn 2.0%, Cu 1.0% , 100 ppm Co, 500 ppm I 100 ppm Se), 2.4% vitamin premix (8,800,000 IU/kg vitamin A, 1,760,000 IU/kg vitamin D, 1,100 IU/kg vitamin E), 18.7% vitamin E premix (44,000 IU/kg)

Table 3. 2. Feeder effects on hay waste, refusal, and DMI in Exp. 1

Item	Feeder ¹		SEM ²	P-value ³
	SRF+C	SRF		
Bale, kg	442.3	446.0	10.1	0.80
ORT, kg ⁴	109.7	99.1	8.8	0.40
DMI ⁵				
kg/(cow·d)	10.0	9.8	0.2	0.45
%BW ⁶	1.60	1.55	0.01	0.45
Waste				
kg/bale	75.1	84.9	4.1	0.11
kg/(cow·d)	2.8	3.1	0.1	0.14
%bale ⁷	16.1	18.3	1.0	0.11
%DMI ⁸	27.6	32.1	1.8	0.09

¹ Feeder sheeted upper and lower section, and individual feeding stations (Hay Hopper; Action signs and Billboards, Chandler, MN)
SRF+C = with cradle chain, SRF = removed cradle chain

² Largest standard error of least squared means

³ Observed significance level for feeder

⁴ ORT = forage remaining in feed when visual estimated to limit DMI in next 24 h

⁵ Calculated DMI = initial bale – (waste + ORT)

⁶ DMI expressed as percentage of initial BW

⁷ Forage waste expressed as percentage of initial bale DM

⁸ Forage waste expressed percentage of calculated DMI

Table 3. 3. Bale diameter effects on hay waste, refusal, and DMI in Exp. 1

Item	Bale diameter ¹			SEM ²	P-value ³
	SML	MDM	LGE		
Bale, kg	274.2 ^c	435.9 ^b	622.4 ^a	12.3	<0.001
ORT, kg ⁴	73.9 ^b	128.2 ^a	111.1 ^a	10.7	0.01
DMI ⁵					
kg/(cow·d)	10.1	10.0	9.7	0.3	0.68
%BW ⁶	1.60	1.58	1.54	0.01	0.68
Waste					
kg/bale	39.2 ^c	79.0 ^b	121.8 ^a	4.1	<0.001
kg/(cow·d)	2.4 ^b	3.3 ^a	3.1 ^a	0.2	0.01
%bale ⁷	14.3 ^b	17.6 ^{ab}	19.7 ^a	1.2	0.001
%DMI ⁸	25.0 ^b	33.0 ^a	31.6 ^a	2.3	0.04

^{a-c}Within a row means without common superscript differ ($P < 0.05$)

¹Bale diameter: SML = 129 cm, MDM = 158 cm, LGE = 188 cm; Width = 152 cm

²Largest standard error of least squared means

³Observed significance level for bale diameter

⁴ORT = forage remaining in feed when visual estimated to limit DMI in next 24 h

⁵Calculated DMI = initial bale – (waste + ORT)

⁶DMI expressed as percentage of initial BW ⁷Forage waste expressed as percentage of initial bale DM

⁸Forage waste expressed percentage of calculated DMI

Table 3. 4. Stocking rate and feeder design affects hay waste, refusal, and DMI (DM basis) in Exp. 2

Item	Feeder and stocking rate treatment						SEM ⁴	<i>P</i> -value ²		
	SRF+C ¹			OPN				Stocking rate	Feeder	SR x F
	SR-8 ³	SR-16	SR-24	SR-8	SR-16	SR-24				
Bale, kg	472.7	490.7	497.0	481.9	508.8	501.3	17.2	0.57	0.46	0.92
ORT, kg ⁵	133.4	55.6	180.8	115.1	54.6	146.0	13.5	<0.01	0.21	0.55
DMI										
kg/(cow·d) ⁶	12.1	11.5	11.5	12.4	11.5	11.5	0.5	0.21	0.81	0.96
%BW ⁷	2.07	1.96	1.96	2.11	1.96	1.96	0.08	0.22	0.81	0.95
Waste										
kg/bale	47.8	66.5	39.4	69.0	85.1	79.4	5.5	<0.01	<0.01	0.15
kg/(cow·d)	2.0 ^c	2.1 ^{bc}	1.7 ^c	2.9 ^{ab}	2.7 ^{ab}	3.3 ^a	0.2	0.83	<0.01	0.05
%bale ⁸	10.3	13.7	8.3	14.6	16.7	16.0	1.1	0.03	<0.01	0.13
%DMI ⁹	16.4 ^c	18.3 ^{bc}	14.7 ^c	23.4 ^{ab}	23.6 ^{ab}	29.2 ^a	2.1	0.63	<0.01	0.10

¹ Feeder: SRF+C = sheeted upper and lower section, cradle chain and individual feeding stations separated by vertical bars (Hay Hopper; Action signs and Billboards, Chandler, MN). OPN = open ring with slanted feeding stations (Hay Ring; Hatton Vermeer Sales, LLC, Auxvasse, MO)

² Observed significance level for stocking rate (SR), feeder (F), and the 2-way interaction

³ SR-8 = 8 cows/pen, SR-16 = 16 cows/pen, SR-24 = 24 cows/pen

⁴ Largest standard error of least squared means

⁵ ORT = forage remaining in feed when visual estimated to limit DMI in next 24 h

⁶ Calculated DMI = initial bale – (waste + ORT)

⁷ DMI expressed as percentage of initial BW

⁸ Forage waste expressed as percentage of initial bale DM

⁹ Forage waste expressed percentage of calculated DMI

Figure 3.1. Round bale feeder designs: Sheeted upper and lower sections and vertical bars separating 16 individual feeding spaces (a) with cradle chain (SRF+C), or (b) without cradle chain (SRF) (Hay Hopper; Actions signs and Billboards, Chandler, MN) and (c) OPN = open ring with slanted bars separating 17 individual feeding spaces (Hay Ring; Hatton Vermeer Sales, LLC, Auxvasse, MO).

Figure 3.2. Least squared means of small bale waste over 2 d period. SRF+C = with cradle chain, SRF = without cradle chain. Sheeted upper and lower sections and vertical bars separating 16 individual feeding spaces. (Hay Hopper; Actions signs and Billboards, Chandler, MN). Feeder x day interaction P -value < 0.01. ^{abc}Means without common superscript differ ($P < 0.05$).

— Cone - - Ring

Figure 3.3. Least squared means of medium bale waste over 3 d period. SRF+C = with cradle chain, SRF = without cradle chain. Sheeted upper and lower sections and vertical bars separating 16 individual feeding spaces. (Hay Hopper; Actions signs and Billboards, Chandler, MN). Feeder x day interaction P -value = 0.08. ^{ab}Means without common superscript differ ($P < 0.05$).

— Cone - - Ring

Figure 3.4. Least squared means of large bale waste over 5 d period. SRF+C = with cradle chain, SRF = without cradle chain. Sheeted upper and lower sections and vertical bars separating 16 individual feeding spaces. (Hay Hopper; Actions signs and Billboards, Chandler, MN). Feeder x day interaction P -value = 0.09. ^{abcd}Means without common superscript differ ($P < 0.05$).

— Cone - - Ring



(a)



(b)



(c)

Figure 3.1.

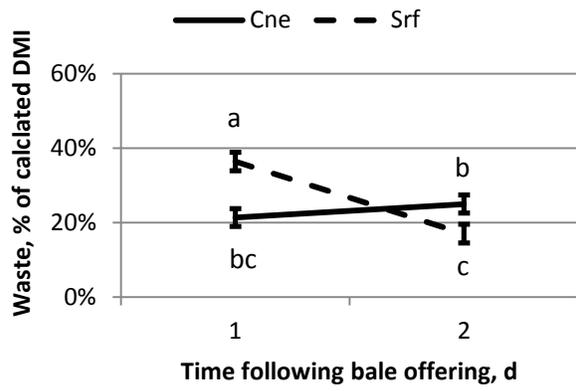


Figure 3.2.

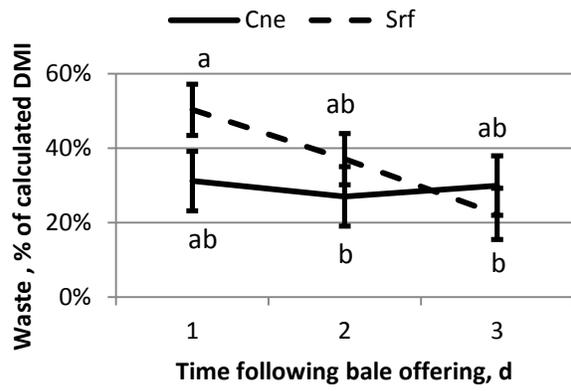


Figure 3.3.

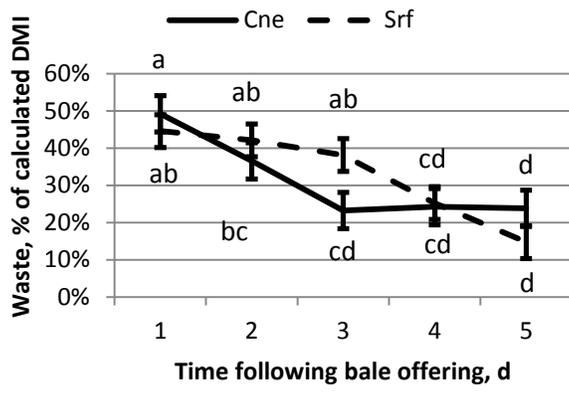


Figure 3.4.

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