

Effects of bale feeder design on hay waste, intake, and apparent diet digestibility in gestating beef cows

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ABSTRACT: Two experiments were conducted to determine the effects of feeder design on hay intake, apparent diet digestibility, and hay waste in gestating beef cows. Native tallgrass prairie hay and a protein supplement was fed throughout both experiments. In Exp. 1, 56 crossbred cows were used in a Latin square arrangement. Feeder design treatments included a conventional open bottom steel ring (**OBSR**), an open bottom polyethylene pipe ring (**POLY**); a sheeted bottom steel ring (**RING**), and a sheeted bottom steel ring with a basket (**BASK**). Cows were weighed and allotted based on BW to one of four previously grazed 2.0 ha paddocks equipped with a concrete feeding pad. Fourteen cows were assigned to each paddock and three round bales were fed consecutively within each treatment period. The cows acclimated to the feeders while the first bale was being consumed. Subsequently, hay waste data were collected while the second and third bale within each period were being consumed. Waste was measured for each bale at 24, 48, 72, and 96 h after each bale was introduced into the pen. Hay waste was significantly affected by hay feeder design with

19.7, 21.1, 12.4, and 5.5% of original bale weight wasted for OBSR, POLY, RING, and BASK, respectively ($P < 0.01$). There was a feeder design \times day interaction ($P < 0.01$) with greater waste when the bale was first introduced into the pen in OBSR, POLY, and RING feeders and gradually declining thereafter, while waste from the BASK feeder was consistently low. There was a tendency ($P = 0.06$) for cows eating from OBSR feeders to consume less hay than cows eating from RING feeders. Feeder design did not influence apparent diet digestibility ($P = 0.46$). In Exp. 2, 64 crossbred cows (body weight = 590 ± 59 kg) were used to determine waste, forage intake, and apparent diet digestibility when hay was fed from a sheeted bottom steel ring (**RING**) or a RING feeder with a cone insert (**CONE**). More hay was wasted when cows were fed from RING feeders compared to CONE feeders (11.9% vs. 4.8%, $P < 0.01$). Feeder design had no effect on DMI or apparent digestibility ($P > 0.45$). Hay savings from adopting a more conservative feeder design can have a dramatic influence on hay utilization by beef cows and thus on cost of production.

Key words: beef cattle, diet digestibility, feeder design, feed intake, hay waste

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INTRODUCTION

Harvesting forage during the summer months for feeding during fall, winter, or early spring is a common practice in cow/calf enterprises. Costs associated with feed and pasture account for 40% to 60% of the annual budget in commercial cow/calf operations (Miller et al., 2001; Bevers, 2010; Bowman et al., 2019). Survey data from Oklahoma reported that 45% of all producer respondents fed hay between 91 and 120 d each winter (Vestal, 2007). The large round bale is the form of hay typically provided to cows in the Southern Great Plains and in the Midwest during the winter months. Common feeding techniques include unrolling bales and feeding whole bales in various designs of hay feeders. Compared to rolling bales out on the ground or shredding bales on the ground, the use of a hay feeder with a cone insert decreased hay waste, decreased the amount of hay required per cow, and decreased wintering cost per cow (Landbolm et al., 2007). However, there are dozens of hay feeder designs on the market today ranging from approximately \$250 to \$2500 each. Buskirk et al. (2003) compared four different feeder designs and found that the ring feeder with a cone insert resulted in less hay waste compared to a conventional ring feeder design (3.5% and 6.1% hay waste, respectively). According to Oklahoma survey data, the most popular design of round-bale feeder is the conventional ring with no bottom skirt and no cone or basket mechanism (Sexten, A. J., unpublished data). Cost, weight, ease of handling, and durability were considered the top four factors in selecting a round-bale feeder. The objective of this study was to determine the effects of hay feeder design on hay waste, hay intake, and apparent diet digestibility.

MATERIALS AND METHODS

Two experiments were conducted at the OSU Range Cow Research Center; North Range Unit located approximately 16 km west of Stillwater, Oklahoma in accordance with an approved Oklahoma State University Animal Care and Use Committee protocol (AG0918). Native tallgrass prairie hay was harvested from a single hay meadow during mid-July the summer prior to the feeding experiments. Hay was baled using a conventional round baler (John Deere Model 568, Ottumwa, IA). Average bale diameter was approximately 1.8 m and average bale width was 1.58 m. The round bales were removed from the field within 1 wk of baling and stacked end-to-end uncovered in a well-drained

storage area until feeding. Throughout both experiments, body condition scores (BCS; Wagner et al., 1988) were determined by two trained evaluators and averaged for each date.

Experiment One

Fifty-six Angus and Angus x Hereford beef cows (initial BW = 494 ± 50 kg; BCS = 5.2 ± 0.5) in the second trimester of pregnancy were used in a 4×4 Latin square arrangement with four hay feeder designs and four periods. Fourteen cows were allotted based on BW to one of four previously grazed 2.0 ha paddocks equipped with a 12.2×7.6 m² concrete feeding pad and a self-filling water tank. During each period, cows had ad libitum access to native tallgrass prairie hay (5.5% crude protein [CP], 43.6% acid detergent fiber [ADF], 66.2% neutral detergent fiber [NDF], 3.74% acid detergent insoluble ash [ADIA], dry matter [DM] basis) and were provided 1.36 kg/head daily of a 36% CP cottonseed meal-based pellet for the duration of the study. Pellets were fed in a concrete feed bunk with approximately 87 cm of bunk space for each cow.

The four bale feeder designs used in Exp. 1 can be seen in Fig. 1. Each paddock was initially randomly assigned one of the four feeder designs which included: a conventional open bottom steel ring (OBSR), a polyethylene pipe open bottom ring (Century Livestock Feeders, Shidler, OK; POLY), a sheeted bottom steel ring (Model Super-10 Bale Feeder, Franklin Industries, Monticello, IA; RING), and a feeder with a basket feature in addition to a sheeted bottom ring (Bextra, Lienemann Management Productions, LLC, Princeton, NE; BASK). The diameter of the OBSR was 2.44 m, with an overall height of 101.6 cm. The POLY feeder diameter was 2.36 m, with an overall height of 113 cm. The diameter of the RING was 2.44 m, with an overall height of 130.2 cm. The diameter of the BASK was 2.66 m and had an overall height of 144.8 cm. The RING feeder had 16 individual feeding stations that were 48.3 cm wide. The remaining three feeders did not have individual feeding stations.

Within each paddock during each experimental period, three large round bales of hay were fed consecutively. All net wrap was removed prior to feeding each bale of hay. Throughout the experiment, bales were set horizontally with a tractor front end loader on the concrete pad and feeders were subsequently lowered over the bale of hay (OBSR and POLY). Bales were lowered into the feeders and set horizontally in RING and BASK feeder designs.

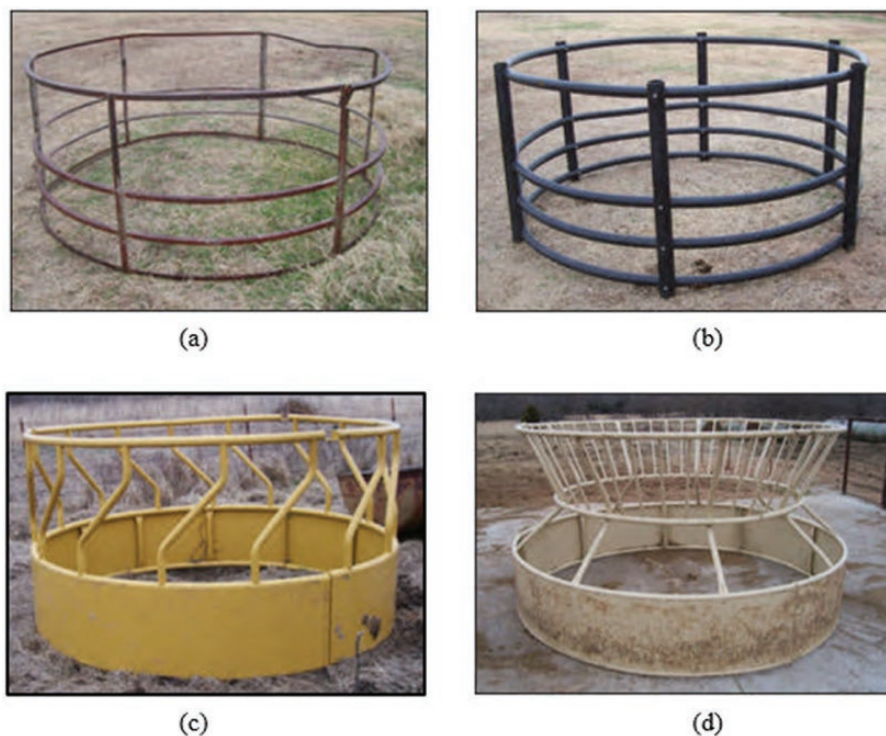


Figure 1. Round bale feeder designs used in Exp. 1: (a), conventional open bottom steel ring feeder; OBSR; (b) open bottom polyethylene pipe ring feeder; POLY (Century Livestock Feeders, Shidler, OK); (c) sheeted bottom steel ring feeder; RING (Franklin Industries, Monticello, IA); (d) sheeted bottom feeder with basket feature; BASK (Lienemann Management Productions, LLC, Princeton, NE).

The source of hay, the supplement and the small pasture remained consistent for each group of cows throughout the experiment. The only change from one period to the next was the design of hay feeder. Therefore, the adaptation period was intended to familiarize the animals with the hay feeder because there was no change in diet throughout the experiment. Cows were adapted to the hay feeders from day 0 to day 5 while consuming the first bale. At approximately 1,500 on day 5, the hay feeders were removed from the concrete pads and all remaining hay was discarded. The concrete pad was cleaned to remove manure, soil, and hay particles. Once the concrete pads were cleaned the hay feeder was returned to the pad. Immediately prior to feeding on day 5, the second bale was weighed on an electronic scale and three core hay samples were collected (Colorado Hay Probe; Nasco, Fort Atkinson, WI). The second bale was then placed in the hay feeder within each pen.

Hay waste was collected daily at 1500 h from around each feeder on day 6, 7, 8, and 9. Waste was defined as any hay on the concrete or pen surface outside of the feeder perimeter. To minimize error associated with wide ranges in waste sample dry matter content, hay waste was sorted into dry and wet subgroups based on visual evaluation. Wet waste was generally contaminated with urine, feces or moisture from precipitation and contained

approximately $\geq 20\%$ moisture. Special attention was given to avoid the inclusion of manure or other foreign materials that could be separated by hand. Dry and wet waste was then placed in separate plastic containers and weighed on an electronic scale. After waste was collected on day 9, the hay feeder was removed from the concrete pad and all hay remaining inside the feeder (orts) was weighed on an electronic scale and subsampled before being discarded. Immediately after collection, core samples, dry waste samples, wet waste samples, and ort samples were stored in a paper bag labeled according to sample type, date, pen, and hay feeder treatment. After concrete pads had been cleaned on day 9, the hay feeder was returned, the third bale (for that period and paddock) was weighed on the electronic scale, core samples collected, and the process was repeated as described for the previous period. Waste weight and subsamples for the second bale were collected at 1500 h on day 10, 11, 12, and 13 and ort samples were collected and discarded on day 13.

Dry matter and organic matter (OM) digestibility was determined using acid detergent insoluble ash (ADIA) as an internal marker to calculate average fecal output as described by [Kanani et al. \(2015\)](#). Beginning on day 8 of each period and continuing through day 13, fecal grab samples were collected daily at 0800 and 1600 h.

During each collection, a minimum of six fresh fecal pats were sampled and thoroughly mixed to create a pooled sample for the pen. Care was taken to avoid soil contamination by collecting material from the top, central portion of each manure pat.

Average hay intake per cow was calculated by subtracting orts and total waste from the original bale weight, then divided by the number of cows in the pen. Daily digestible organic matter intake (**DOMI**) was calculated as daily DM intake multiplied by organic matter digestibility.

After pads were cleaned on day 13, hay feeders were rotated clockwise to the next paddock and the next period was initiated using the same procedures and schedule. Cows remained in the same paddock throughout the experiment.

A sensitivity analysis was conducted to determine the influence of hay cost on projected 5-yr value of hay waste for each feeder design. Five years was assumed to represent a conservative useful life or period the feeders remained in service. Length of the hay feeding period was assumed to be 90 d and feeder stocking rate was assumed to be 20 cows. Average daily hay waste per cow was calculated according to the following equation:

$$(DMI/[1 + \text{hay waste}/100]) - DMI$$

Where DMI = study-average DM intake, kg/d, and hay waste = percent total waste for each feeder design. Study-average DM intake was used in the sensitivity analysis because average daily DM intake was not significantly affected by feeder design ($P = 0.06$). The OBSR and POLY treatments did not differ in total hay waste ($P = 0.36$) and therefore, least square means for these treatments were averaged to calculate 5-yr value of hay waste.

Experiment Two

Sixty-four Angus and Angus \times Hereford beef cows (initial BW = 598 ± 62 kg; BCS = 5.2 ± 0.8) in the third trimester of pregnancy were used with two hay feeder designs, four pasture groups, and four experimental periods in a replicated crossover design. Sixteen cows were randomly assigned to one of four previously grazed 2.0 ha paddocks that each contained a 12.2×7.6 m² concrete feeding pad and a self-filling water tank. Cows were provided ad libitum access to native tallgrass prairie hay and received 0.91 kg/d of 30% CP supplemental dried distiller's grains with solubles (**DDGS**) daily for the duration of the study. Pellets were fed in a concrete feed bunk with approximately 76 cm of bunk space for each cow.

The forage nutritive value for the native tallgrass prairie hay was: 6.3% CP, 43.6% ADF, 69.7% NDF, DM basis.

The two bale feeder designs used in Exp. 2 can be seen in Fig. 2. Two of the four pastures were initially assigned one of two round bale feeder designs: a sheeted bottom steel ring feeder (Model Super-10 Bale Feeder; Franklin Industries, Montecello, IA; **RING**) and the RING feeder equipped with a cone insert (Model Super-10/CY-8 Unit; Franklin Industries, Montecello, IA; **CONE**). The diameter of the RING and the CONE was 2.44 m, with an overall height of 130.2 cm and 168 cm, respectively. The RING and CONE feeder was constructed with 16 individual feeding stations that were 48.3 cm wide.

Four collection periods were used consisting of 10 d of feeder design adaptation and four d of data collection. Cows were offered ad libitum access to tallgrass prairie hay throughout the experiment. On approximately 1500 h on day 10 the remaining hay in the feeder was removed and all manure was cleaned off the concrete



Figure 2. Round bale feeder designs used in experiment 2: (a) sheeted bottom steel ring feeder; RING (Franklin Industries, Montecello, IA); (b) sheeted bottom steel ring feeder equipped with a cone insert; CONE (Franklin Industries, Montecello, IA).

pads. After cleaning the concrete pad, the hay feeder was returned. The first experimental bale was weighed on an electronic scale, core sampled and placed in the feeder within each pasture. Waste was defined as hay on the concrete or pen surface outside the feeder perimeter and orts were defined as hay remaining inside the feeder. Waste was collected, weighed, and sampled from around each feeder at 1500 h on day 11 and again on day 12 of each period. After waste was collected on day 12, the hay feeder was removed and orts were collected, placed in large plastic containers, weighed on an electronic scale, sampled for dry matter content, and then removed from the pasture (discarded). Once the concrete pad was cleaned, the hay feeder was returned to the concrete pad and the second experimental bale for that period was weighed, core sampled and placed in the hay feeder. Waste measurements were determined at 1500 h on day 13 and day 14 and ort weights were collected at approximately 1600 on day 14. Similar to Exp. 1, all hay waste was sorted into dry and wet (manure and urine contaminated) piles prior to being placed in plastic containers for weighing and subsampling to determine DM content.

Similar to Exp. 1, DM and OM digestibility was determined using ADIA as an internal marker to calculate average fecal output as described by [Kanani et al. \(2015\)](#). Fecal grab samples from a minimum of six fresh manure pats within each pasture were collected and pooled twice daily within each paddock at 0800 and 1600.

A sensitivity analysis was conducted to determine the influence of hay cost on projected 5-yr value of hay waste for each feeder design using the same procedures as described for Exp. 1. Length of the hay feeding period was assumed to be 90 d and feeder stocking rate was assumed to be 20 cows. Like Exp. 1, study-average DM intake was used in the sensitivity analysis because DM intake was not significantly affected by feeder design ($P = 0.20$).

Sample Analysis

For both experiments, initial bale core, dry and wet waste, orts, and fecal subsamples were dried in a forced-air oven at 50 °C. Samples were weighed twice daily and considered to be dry when no further weight loss occurred. Following drying, samples were ground through a Wiley Mill (Model 4, Thomas Specific, Swedesboro, NJ) using a 2 mm screen for initial bale core, ort, dry waste and wet

waste samples, and a 1 mm screen for fecal samples and stored for further analysis. Initial bale cores, waste, orts, and fecal samples were analyzed for NDF and ADF (Ankom Tech Corp, Fairport, NY), ash (combusted 6 h in a muffle furnace at 500 °C), and CP (% N \times 6.25; TruSpec CN, LECO Corporation, St. Joseph, MI). Acid detergent insoluble ash contents in initial bale cores, waste, orts, and fecal samples were determined by ashing ADF residues in a muffle furnace at 500 °C for 8 h. The results were used to calculate apparent digestibility of CP, NDF, ADF, and ADIA in Exp. 1 and DM and OM in Exp. 2.

Statistical Analysis

In Exp. 1, hay waste, orts, hay consumed, mean daily hay intake, and apparent digestibility were analyzed as a Latin square design using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC), with four paddocks (columns) and four periods (rows). Paddock was the experimental unit and because waste and intake from two bales were measured during each period, bale within paddock was considered the pseudo-replicate. The model statement contained the fixed effect of feeder design (OBSR, POLY, RING, and BASK), and the random statement included paddock and period. Twenty-four hours feeding period (24, 48, 72, and 96 h) waste was analyzed as a 4 \times 4 Latin square design with repeated measurement over time. The main plot contained the effect of column and row and the subplot contained the effects of time and interactions with feeder treatment. For significant effects, treatment means were compared using least significant different multiple comparisons. The alpha level to determine statistical significances was set to $\alpha = 0.05$ and tendencies were reported at $0.05 < P\text{-value} < 0.10$.

In Exp. 2, data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc.), with paddock considered the experimental unit. The model statement contained the fixed effect of feeder design (RING and CONE). The random statement included paddock and period. Paddock was the experimental unit and because waste and intake from two bales were measured during each period, bale within paddock was considered the pseudo-replicate. Similar to Exp. 1, treatment means were compared using least significant different multiple comparisons. The alpha level to determine statistical significances was set to $\alpha = 0.05$ and tendencies were reported at $0.05 < P\text{-value} < 0.10$.

RESULTS

The effects of Exp. 1 feeder design on hay waste are shown in [Table 1](#). The two open-design feeders (OBSR and POLY) resulted in similar total hay waste ($P = 0.65$) and significantly more of the original bale weight wasted compared to the RING feeder ($P = 0.01$). However, total hay waste from the RING feeder was greater ($P < 0.01$) when compared with the BASK-design feeder.

There was a feeder design \times day interaction ($P < 0.01$) with greater waste ($P < 0.05$) in the OBSR, POLY, and RING feeders during the first, second, and third 24-h periods compared to the BASK-design feeder ([Fig. 3](#)). This resulted in more ($P < 0.01$) consumable hay (orts) remaining in the BASK after 96 h of feeding time compared to the other three feeder designs ([Table 1](#)).

A greater percentage ($P < 0.05$) of the original bale DM weight was consumed by the cattle after 96 h of feeding time when using the BASK feeders compared to the OBSR and when using RING feeders compared to OBSR and POLY feeders. There was a tendency ($P = 0.06$) for cattle to consume more kg forage per day when using the RING vs the OBSR feeder, although hay feeder design did not influence mean daily hay intake when expressed as a percent of initial cow BW ($P = 0.12$; [Table 2](#)). Neither diet DM nor OM digestibility were influenced ($P \geq 0.85$) by hay feeder design ([Table 2](#)). However, digestible organic matter intake, kg/d and DOMI, % BW was greater ($P = 0.01$) for cattle fed with the RING feeder compared to OBSR, POLY, and BASK.

Compared to the OBSR and POLY designs, the BASK design resulted in \$744 and \$1,737 savings in hay value over a 5-yr period when hay was priced at \$60 and \$140 per 908 kg, respectively ([Table 3](#)).

Results for hay waste from Exp. 2 are shown in [Table 4](#). Use of RING feeders reduced total hay waste by 60% ($P < 0.01$) compared to CONE feeders. The RING feeder produced more waste ($P < 0.01$) during the first 24 h feeding period, although there was not a significant difference in waste ($P = 0.11$) during the second 24 h feeding period. Feeder design did not influence DM or OM intake expressed as kg/d ($P > 0.17$) or as a percent of BW ($P = 0.17$; [Table 5](#)). Similarly, neither apparent DM digestibility nor OM digestibility was influenced by feeder design ($P \geq 0.91$).

The CONE design resulted in \$445 and \$1,039 savings in hay value over a 5-yr period when hay was priced at \$60 and \$140 per 908 kg, respectively ([Table 6](#)).

DISCUSSION

Considering the popularity of large round baling in U.S. agriculture as a method to harvest, store and feed forage, few experiments have been published documenting hay feeding waste with different feeder designs. The OBSR and POLY feeders used in this experiment were constructed of different material, although of similar design, with no sheeted bottom, no individual feeding stations and no sheeting or other structure to restrict cows' access to bales above approximately 91 cm. Therefore, it is not surprising that hay waste was similar between these two feeder designs. [Moore and Sexton \(2015\)](#) also reported 19.2% of fescue hay wasted when gestating cows were fed using feeders of similar open design to the OBSR and POLY feeders used in the current experiment. [Miller et al. \(2007\)](#) reported 16.4% and 39.2% waste in two studies where gestating cows were

Table 1. Effects of feeder design on hay waste, orts, and disappearance, Exp. 1

Item	Feeder Design ¹				SEM ²	P-value
	OBSR	POLY	RING	BASK		
No. of bales measured ³	8	8	8	8		
Bale DM weight, kg	621.0	634.9	611.8	602.9	21.6	0.15
Total waste, % of bale DM ⁴	19.7 ^a	21.1 ^a	12.4 ^b	5.5 ^c	1.34	<0.01
Orts, % of bale DM ⁵	6.49 ^a	4.62 ^a	7.18 ^a	16.6 ^b	1.60	<0.01
Forage DM consumed, % of bale DM	73.8 ^a	74.4 ^{a,b}	80.4 ^{c,d}	77.9 ^{b,e}	2.05	<0.01

¹OBSR = conventional open bottom steel ring feeder; POLY = polyethylene pipe ring feeder; RING = sheeted bottom steel ring feeder; BASK = sheeted bottom steel ring feeder with a basket feature.

²SEM of the Least squares means.

³Hay waste measured for two bales during each period over four periods.

⁴Total hay waste through 96 h after bale introduction, expressed as percent of initial bale DM weight.

⁵Orts = hay DM remaining inside the feeder 96 h after bale introduction to the paddock.

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

fed large round bales of hay in a fenceline feeder system with ad libitum access to hay and 0.6 m of hay feeder space per cow.

With the exception of the BASK design feeder, hay feeding waste was greatest early after bale introduction to the pen and gradually declined for each 24-h period. Greater waste early after bale introduction in OBSR, POLY and RING designs is likely related to proximity of the external portions of the bale to the feeder perimeter, lack of internal feeding space (Buskirk et al., 2003; Martinson et al., 2011; Moore and Sexten, 2015), and the top one third of the bale being accessible to the cows near the feeder perimeter.

The RING feeder with sheeted bottom resulted in an average 39% reduction in hay feeding waste compared to the two open-design feeders. Comparisons between open-design and sheeted-design feeders are few. Moore and Sexten (2015) found similar results comparing an open-design feeder to a tapered feeder with a solid-sheeted bottom with 19.2% and 13.6% waste, respectively. We documented similar hay waste using RING feeders in Exp. 1 (12.4%) and Exp. 2 (11.9%). Buskirk et al. (2003) used a similar design feeder with individual feeding stanchions and a solid metal sheet covering the bottom 61 cm. In their experiment, only 6.1% of hay that disappeared was determined to be

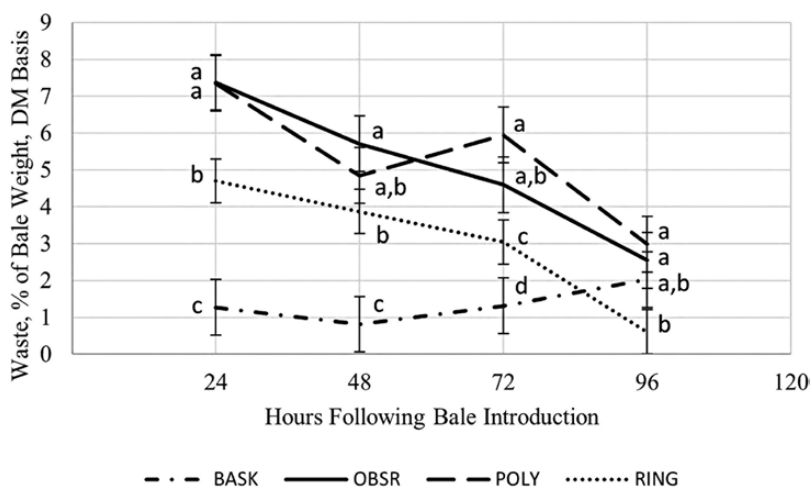


Figure 3. Least square means for hay waste, expressed as a percent of original bale weight, by hours after bale introduction to the pen. BASK = feeder with sheeted bottom and a basket feature; OBSR = conventional open bottom steel ring feeder; POLY = polyethylene pipe open bottom ring feeder; RING = sheeted bottom steel ring feeder. Feeder \times day interaction, $P < 0.01$. Within day, means without a common superscript differ ($P < 0.05$).

Table 2. Effects of feeder design on hay intake and apparent digestibility, Exp. 1

Item	Feeder design ¹				SEM ²	P-value
	OBSR	POLY	RING	BASK		
No. of bales measured ³	8	8	8	8		
Intake ⁴						
DMI, kg/d	8.16	8.42	8.78	8.40	0.49	0.06
DMI, % BW	1.62	1.67	1.74	1.67	0.05	0.12
DOMI, kg/d	10.6 ^a	10.8 ^a	11.5 ^b	10.6 ^a	0.29	0.01
DOMI, % BW	0.95 ^a	0.97 ^a	1.03 ^b	0.95 ^a	0.03	0.01
Apparent Digestibility ⁵						
DM, %	56.0	55.6	57.0	54.6	1.7	0.82
OM, %	58.7	58.2	59.3	57.0	1.8	0.86

¹OBSR = conventional open bottom steel ring feeder; POLY = polyethylene pipe open bottom ring feeder; RING = sheeted bottom steel ring feeder; BASK = sheeted bottom feeder with basket feature.

²SEM of the Least squares means.

³Hay waste measured for two bales during each period over four periods.

⁴DMI = daily dry matter intake, kg/d; DMI, % BW = daily dry matter intake expressed as a percentage of BW; DOMI, kg/d = daily digestible organic matter intake, kg/d; DOMI, % BW = daily digestible organic matter intake expressed as a percentage of BW.

⁵DM = dry matter digestibility, % of total DM; OM = organic matter digestibility, % of total OM.

^{ab}Within a row, means without a common superscript differ ($P \leq 0.03$).

wasted when RING feeders were used. The reason for lower hay feeding waste in the study of Buskirk et al. (2003) is unclear.

In the current studies, the BASK design feeder reduced hay feeding waste by an average of 73% compared to the open-design feeders and by 37% compared to the RING feeder. Similarly, in Exp. 2, the CONE feeder reduced hay feeding waste by 60% compared to the RING design feeder. These results agree with those of Moore and Sexten (2015) reporting 8.9% waste in grass hay fed through a sheeted bottom and sheeted-top chain cone feeder compared to 13.6% waste when fescue hay was fed with a sheeted bottom tapered ring-design feeder. Buskirk et al. (2003) reported that feeding large round bales with a cone design feeder yielded the least amount of waste when compared to a conventional sheeted bottom ring (3.5% and 6.1% waste, respectively). Comerford et al. (1994), also found that CONE feeders were more effective than RING feeders at reducing waste reporting losses of 1.9% and 8.0%, respectively. In another experiment, Sexten et al. (2011) reported cow/calf pairs with ad libitum access to native range hay out of a BASK feeder had 5.0% waste expressed as a percent of bale wt. Results from Landbolm et al.

(2007) also show a tapered cone design feeder to be the most efficient regarding limiting hay waste when feeding large round bales of alfalfa-grass hay. These authors compared a tapered cone feeder to unrolling bales on the ground and processing hay into windrows using a power-take-off-driven bale processor. The tapered cone had 4.3 to 5.0 times less hay waste than that of either rolling out on the ground or using a bale processor (Landbolm et al., 2007).

Hay waste could be influenced by several different feeder design features. First, the three most efficient feeders (BASK and RING, Exp. 1; and CONE, Exp. 2) all have sheeted bottom sections, which aid in containing the hay within the feeder. The lower sheeting reduces waste later in the feeding period when the bale has collapsed, and there is increased space for cattle to eat inside of the feeder (Moore and Sexten, 2015). When feeding horses, round bale feeders provided a physical barrier in reducing trampling and contamination of urine and feces (Martinson et al., 2011). The lower sheeting in the feeders (BASK, RING, CONE) of the current experiments help contain orts inside the feeder perimeter, thus reducing chances of feces and urine contamination. The RING and CONE feeders have

Table 3. Five-year value of wasted hay by hay cost and feeder design, Exp. 1¹

Hay cost, \$/908 kg	Feeder design			
	OBSR	POLY	RING	BASK
60	1019	1019	619	275
80	1359	1359	826	366
100	1699	1699	1032	458
120	2038	2038	1239	550
140	2378	2378	1445	641

¹Values in the table are U.S. dollars per five-year period. Assumptions: twenty cows per feeder, 617 kg average bale weight, average daily hay consumed per cow = 8.4 kg, 90 days of hay feeding per year. Hay waste was averaged for the OBSR and POLY treatments (20.4% of original bale weight; $P = 0.44$).

Table 4. Effects of feeder design on hay waste, orts, and disappearance, Exp. 2

Item	Feeder design ¹		SEM ²	<i>P</i> -value
	RING	CONE		
No. of bales measured ³	8	8		
Bale DM weight, kg	534.7	536.8	15.6	0.89
First 24-h waste, % of bale DM ⁴	7.70	2.14	0.92	< 0.01
Second 24-h waste, % of bale DM ⁴	4.16	2.62	0.65	0.11
Total 48-h waste, % of bale DM ⁴	11.9	4.77	0.6	< 0.01
Orts, % of bale DM ⁵	24.6	29.4	1.5	0.16
Forage DM consumed, % of bale DM	63.6	65.9	1.3	0.26

¹RING = sheeted bottom steel ring feeder; CONE = RING feeder equipped with a cone insert.

²Standard error of least squares means

³Hay waste measured for two bales during each period over four periods.

⁴Hay waste expressed as a percentage of initial bale weight for first 24 h, second 24 h and total 48 h.

⁵Orts = hay DM remaining inside the feeder 48 h after bale introduction to the paddock.

Table 5. Effects of feeder design on hay intake and apparent diet digestibility, Exp. 2

Item	Feeder design ¹		SEM ²	P-value
	RING	CONE		
No. of bales measured ³	8	8		
Intake ⁴				
DMI, kg/d	9.98	10.92	0.32	0.20
DMI, % of BW	1.75	1.85	0.05	0.17
DOMI, kg/d	6.13	6.71	0.27	0.18
DOMI, % of BW	1.02	1.11	.05	0.23
Apparent Digestibility ⁵				
DM, %	58.8	58.6	1.25	0.91
OM, %	61.4	61.4	1.14	0.98

¹RING = sheeted bottom steel ring feeder; CONE = RING feeder equipped with a cone insert.

²Standard error of least squares means.

³Hay waste measured for two bales during each period over four periods

⁴DMI = daily dry matter intake, kg/d; DMI, % BW = daily dry matter intake expressed as a percentage of initial mean BW; DOMI = daily digestible organic matter intake, kg/d; DOMI, % of BW = daily digestible organic matter intake expressed as a percentage of BW.

⁵DM = dry matter digestibility, % of total DM; OM = organic matter digestibility, % of total OM.

Table 6. Five-year value of wasted hay by hay cost and feeder design, Exp. 2¹

Hay cost, \$/908 kg	Feeder design ²	
	RING	CONE
60	743	298
80	991	397
100	1,238	496
120	1,486	596
140	1,734	695

¹Values in the table are U.S. dollars per 5-yr period. Assumptions: twenty cows per feeder, 536 kg average bale weight, average daily hay consumed per cow = 10.5 kg, 90 days of hay feeding per year.

²RING = sheeted bottom steel ring feeder; CONE = RING feeder equipped with a cone insert.

individual feeding stations, which [Buskirk et al. \(2003\)](#) reported as being a critical component to reducing hay waste. These authors reported that the only feeder without individual feeding stations had three times the amount of agonistic interactions and four times as many irregular entrances into the feeder. [Buskirk et al. \(2003\)](#) found that hay waste also was positively correlated to increased agonistic interactions, frequency of regular and irregular entrances, and feeder occupancy. [Schultheis and Hires \(1982\)](#) found that the combination of a slanted bar head gate and a pusher bar between the slanted bar head gate and the hay, designed to make cattle reach for hay reduced waste ($P < 0.01$). The slanted head gates used alone and a vertical bar head gate and pusher bar combination resulted in 16.41% and 12.60% hay waste, respectively. However, when used in conjunction, a slanted bar head gate and a pusher bar reduced waste to 9.20% ($P < 0.01$).

[Moore and Sexten \(2015\)](#) defined “feeding space” as the area inside the feeder that allows for feeding. By increasing feeding space within the feeder, entrance frequency and waste is decreased, as it allows for cattle to eat in a natural grazing position ([Buskirk et al., 2003](#); [Moore and Sexten, 2015](#)). When cattle eat in a natural grazing position, head tossing is reduced, thus reducing waste ([Albright, 1993](#)). [Martinson et al., \(2011\)](#) reported that when horses are able to insert their heads completely into a feeder, head tossing was reduced, and more hay remains inside of the feeder. In the current experiments, the size of the bale in the RING feeders did not allow for adequate feeding space inside the feeder for the first 24 h of access. Additionally, OBSR, POLY, and RING feeder designs provided ample access to hay near the external perimeter where hay could be pulled from the bale and dropped onto the surface of the pen outside the feeder. When compared to the CONE and BASK feeders, more hay could escape the RING due to close proximity of the bales to the outside of the feeder and no restriction of access above 61 cm. Centrally positioning the bale in the BASK feeder, suspending the bale in the CONE feeder, and minimizing access to the top 1/3 of the bale likely contributed to lower feeding waste.

The tendency ($P = 0.06$) for increased DM intake and nonsignificant numerical increase in OM digestibility for the RING feeder resulted in a projected increase in average daily DOMI compared to the other feeder designs. This result conflicts with results from Exp. 2 because DOMI was not different ($P \geq 0.18$) and numerically lower when cattle were

fed from a RING feeder compared to the CONE feeder. Further research is necessary to determine if feeder design has an influence on average daily energy intake when cattle are offered hay on an ad libitum basis.

Hay waste was significantly affected by the feeder design used to provide hay on an ad libitum basis to beef cows. The use of a BASK feeder resulted in the least amount of hay waste during Exp. 1 and was similar to hay waste generated by the CONE feeder design used in Exp. 2. The sensitivity analysis indicates a substantial reduction in production cost due to less hay waste when a more conservative feeder design is used. These values can be used to determine the economic feasibility of purchasing the more expensive feeder designs based on local purchase prices. It should be recognized that this sensitivity analysis does not give credit to any soil fertility value of the wasted hay.

The difference in hay waste comparing the BASK and CONE feeders to open bottom feeders could greatly affect the profitability of a cow/calf operation. Cow DMI and apparent digestibility was not restricted by feeder design and was similar across all treatments. By selecting a hay feeder designed to reduce waste, cow/calf operations can reduce feed loss and therefore reduce cost of production.

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LITERATURE CITED

- Albright, J. L. 1993. Feeding behavior of dairy cattle. *J. Dairy Sci.* 76:485–498. doi:10.3168/jds.S0022-0302(93)77369-5
- Bevers, S. 2010. Southwest Cow-Calf SPA Key Measures Summary (Long Term Average). Accessed January 10, 2021. <https://agrisk.tamu.edu/beef-cow-calf-spa-ranch-economics-and-analysis/ranch-economics-and-analysis-and-beef-cow-calf-spa-information/>
- Bowman, W., D. L. Pendell, K. L. Herbel. 2019. Differences between high-, medium-, and low-profit cow-calf producers: an analysis of 2014–2018 Kansas Farm Management Association cow-calf enterprise. Accessed January 10, 2021. <https://www.agmanager.info/livestock-meat/production-economics/differences-between-high-medium-and-low-profit-cow-calf-1>
- Buskirk, D. D., A. J. Zanella, T. M. Harrigan, J. L. Van Lente, L. M. Gnagey, and M. J. Kaercher. 2003. Large round bale feeder design affects hay utilization and beef cow behavior. *J. Anim. Sci.* 81:109–115. doi:10.2527/jas.2003.811109x
- Comerford, J. W., D. R. Buckmaster, and F. H. Cash. 1994. Effects of three storage methods on nutrient losses from harvest, storage, and feeding of large bales. *J. Anim. Sci.* 72 (Suppl. 2): 130. (Abstr.)
- Kanani, J., D. Philipp, K. P. Coffey, E. B. Kegley, C. P. West, S. Gadberry, J. Jennings, A. N. Young, and R. T. Rhein. 2015. Diurnal variation in fecal concentrations of acid-detergent insoluble ash and alkaline-peroxide lignin from cattle fed bermudagrass hays of varying nutrient content. *J. Anim. Sci. Biotechnol.* 6:24–29. doi:10.1186/s40104-015-0024-1
- Landblom, D. G., G. P. Lardy, R. Fast, C. J. Wachenheim, and T. A. Petry. 2007. Effect of hay feeding methods on cow performance, hay waste, and wintering cost. *Prof. Anim. Sci.* 23:246–252. doi:10.15232/S1080-7446(15)30969-4
- Martinson, K., J. Wilson, K. Cleary, W. Lazarus, W. Thomas, and M. Hathaway. 2011. Round-bale feeder design affects hay waste and economics during horse feeding. *J. Anim. Sci.* 90:1047–1055. doi:10.2527/jas.2011-4087
- Miller, A. J., D. B. Faulkner, R. K. Knipe, D. R. Strohbehn, D. F. Parrett, and L. L. Berger. 2001. Critical control points for profitability in the cow-calf enterprise. *Prof. Anim. Sci.* 17:295–302. doi:10.15232/S1080-7446(15)31643-0
- Miller, A. J., D. B. Faulkner, T. C. Cunningham, and J. M. Dahlquist. 2007. Restricting time of access to large round bales of hay affects hay waste and cow performance. *Prof. Anim. Sci.* 23:366–372. doi:10.15232/S1080-7446(15)30990-6
- Moore, W. A. and W. J. Sexten. 2015. Effect of bale feeder and forage on hay waste, disappearance, and sorting. *Prof. Anim. Sci.* 31:248–254. doi:10.15232/pas.2014-01365
- Sexten, A. J., C. P. McMurphy, G. L. Mourer, C. J. Richards, C. Jones, R. Huhnke, and D. L. Lalman. 2011. Effects of bale feeder type and processing on hay waste, intake, and performance of beef cattle. MS Thesis. Oklahoma State Univ., Stillwater. p. 19–40.
- Schultheis, R. A., and W. G. Hires. 1982. Self feeding headgates for large round hay bales. *Trans. ASABE.* 25:1553–1555. doi:10.13031/2013.33765
- Vestal, M., W. Clement, D. Doye, and D. Lalman. 2007. Cow-calf production practices in Oklahoma Part 1. Accessed January 10, 2021. <https://extension.okstate.edu/factsheets/cow-calf-production-in-oklahoma-part-1.html>
- Wagner, J. J., K. S. Lusby, J. W. Oltjen, J. Rakestraw, R. P. Wettemann, and L. E. Walters. 1988. Carcass composition in mature Hereford cows: estimation and effect on daily metabolizable energy requirement during winter. *J. Anim. Sci.* 66:603–612. doi:10.2527/jas1988.663603x