Influence of hay feeding method, supplement moisture, or access time on intake and waste by beef cows

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ABSTRACT: Experiments were performed to determine the effects of feeding method and hay processing (Experiment 1), energy supplement moisture content and feeding method (Experiment 2), and access time to hay (Experiment 3) on cow body weight (**BW**), dry matter intake (**DMI**), and hay or energy supplement intake and waste. Experiment 1 was designed as a 4 × 4 Latin Square using 48 multiparous, late-gestating, Angus cows (626 kg initial BW). Cows were stratified by age and BW into four treatment groups ($n = 12$ cows/group); treatment groups were then initially assigned randomly to treatments in a sequence of preset Latin Square periods. In Experiment 1, round bales were processed and delivered on the pen surface or in a bunk, or left unprocessed and delivered in a hay ring or rolled out on the pen surface. Experiment 2 was designed as a 6 × 6 Latin Square utilizing 54 multiparous, late-gestating, Angus cows (616 kg initial BW). Cows were stratified by age and BW into treatment groups ($n = 9$ cows/group); treatment groups were then initially assigned randomly to treatments in a sequence of preset Latin Square periods. In Experiment 2, corn screenings (**CS**) or wet beet pulp (**BP**) were fed in a structure (inverted tire or bunk) or BP only on the pen surface. Experiment 3 was designed as a replicated 3 × 3 Latin Square utilizing 24 multiparous, late-gestating, Angus cows (584 kg initial BW). Cows were stratified by age and BW into treatment groups ($n = 8$ cows/group); treatment groups were then initially assigned randomly to treatments in a sequence of preset Latin Square periods. In Experiment 3, cows were permitted access to round-bales in a hay ring for 6, 14, or 24 h. In Experiment 1, hay DMI was not affected ($P \geq 0.579$). Hay waste was greater ($P \leq 0.007$) when hay, processed or not, was fed on the pen surface. In Experiment 2, hay DMI was greatest ($P \leq 0.011$) for cows fed no supplement and those fed CS in a bunk. Feeding BP in a bunk led to the greatest ($P \leq 0.003$) hay waste. In Experiment 3, cows permitted 6-h access consumed and wasted less ($P < 0.001$) hay compared with those permitted longer access; BW was unaffected ($P \geq 0.870$). In these experiments, cows fed hay on the pen surface, processed or not, achieved similar DMI as those fed in a ring or bunk, but wasted more hay. Delivering BP in a bunk or on the pen surface increased hay and supplement waste, respectively. Controlling access to hay reduced DMI and waste while maintaining cow BW.

Key words: access time, beef cows, hay, supplement

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INTRODUCTION

Most cattle producers in the U.S. feed hay in round bales because of simplicity of handling and management. When delivering hay in bale feeders, the feeding unit is a single bale. Because a single mature cow (640 kg) accounts for disappearance through consumption and waste of up to 16.1 kg hay/d (Braungardt et al., 2010), one bale (454 kg) should feed 29 mature cows daily. Alternatives to delivering bales in a feeder are placing hay on the pen surface after either rolling the bale out or processing it. Delivering processed hay in bunks is another option to manage intake at increments concomitant with the number of cows in the group. Cows fed a daily supply of hay in a ring feeder wasted 5%, those fed a daily supply of loose hay on the pen surface wasted 11%, while those fed a 4-d supply of loose hay on the pen surface wasted 31% (Smith et al., 1974). Choice of feeding structure also affects amount of hay waste by cows. Cows given free-choice access to hay delivered every 24 h wasted on average 1.2 kg more hay dry matter (**DM**) from trailer- and cradle-type feeders than those given access to hay in a ring or cone feeder (Buskirk et al., 2003).

Alternatively, limiting access to hay is an option to reduce waste, especially for small herds owned by part-time operators. Cows in their last trimester of gestation were given access to hay in ring feeders for 6, 9, or 24 h (Miller et al., 2007). Longer access time led to greater hay dry matter intake (**DMI**) but cows given access to hay for 9 h wasted the least.

We hypothesized that hay feeding method and processing, energy supplement moisture content and feeding method, and access time to hay influence hay or energy supplement intake and waste. Therefore, objectives of these experiments were to determine whether hay processing and feeding method, supplement moisture content (dry or wet) and feeding method, and access time to hay by late gestating beef cows affected hay and supplement DMI and waste.

MATERIALS AND METHODS

All experimental procedures were approved by the University of Minnesota Institutional Animal Care and Use Committee (IACUC; protocol number: 0812A56422).

Experiment Locations and Weather

Experiment (Exp.) 1 and 2 were conducted at the University of Minnesota North Central Research and Outreach Center (NCROC) in Grand Rapids, and Exp. 3 was conducted at the Rosemount Research and Outreach Center (RROC) in Rosemount. Location coordinates for Exp. 1 and 2 are 47°10′58″N and 93°31′37″W; the center is located at 424 m elevation above sea level. Location coordinates for Exp. 3 are 44°43′05″N and 93°04′09″W; the center is located at 286 m elevation above sea level. Precipitation recorded as rain or snow, snow depth (when present), mean, minimum and maximum temperatures recorded during the experimental periods are listed in Table 1 for each experiment.

Experiment 1. Experiment 1 was designed as a 4 × 4 Latin Square using 48 multiparous, late-gestating, Angus cows (626 kg initial BW) to determine effects of hay feeding method and hay

Table 1. Location and average precipitation as rain or snow, snow cover and average, average low and average high temperatures during Experiment 1 (hay processing and feeding method), Experiment 2 (supplement moisture content and feeding method), and Experiment 3 (ad libitum or managed time access to hay)

Experiment	Location	Rain, mm	Snow, mm	Snow cover, cm	Mean, °C	Low, °C	High, °C
1	Grand Rapids, MN	1.09	7.20	32.83	−8.8	−15.5	−2.1
2	Grand Rapids, MN	2.62	9.27	28.23	−5.9	−11.9	0.1
3	Rosemount, MN	4.52	0.00	0.00	18.1	12.8	23.3

processing on hay intake and waste. Cows (*n* = 12 cows/group) were stratified by age and BW into four groups (group = experimental unit). At the start of the first of four 10-d treatment periods, groups were randomly assigned to one of four pens containing a hay delivery treatment. Subsequent group allocation to pens followed a previously randomly selected 4 × 4 Latin Square design. Cows weight was obtained (XR 3000 Tru-Test Scale, Tru-Test Inc., Mineral Wells, TX) after removing feed for 12 h (to minimize effects of gut fill) at the beginning and end of each 10-d period. Treatments consisted of delivering hay 1) unprocessed in a ring (**U-RING**), 2) unprocessed rolled out on the pen surface (**U-ROLL**), 3) processed and delivered in J-type bunks (**P-BUNK**), or 4) processed and delivered on the pen surface (**P-SRFC**).

Hay rings (Figure 1a) were made of polyethylene pipe and measured 2.44 m diameter × 1.22 m height with four rings and six legs (Century Livestock Feeders Inc., Shidler, OK) or concrete J-bunk (Wieser Heavy-duty Super Bunk, Wieser Concrete Products Inc., Maiden Rock, WI). Whole bales were rolled out on the pen surface by pushing the bales using a pallet fork attachment on a John Deere 320 skid loader (Deere and Company, Moline, IL). Rolled out bale footprint measured approximately 36 m length by 1.8 m width. Hay was processed to an average theoretical length of 12 cm using a Model 2655 Balebuster (DuraTech Industries, Jamestown, ND) and delivered in a windrow measuring approximately 36 m length by 1.8 m width or within 15 m of bunk. Pens were laid out using electric fencing on frozen, snow-covered pastures (undisturbed snow depth average: 33 cm; Table 1). Each pen measured 39.6 m × 100.6 m resulting in stocking rates of 332 m^2/cow. Because of temperatures prevailing during the experiment (Table 1), pen surfaces remained frozen and snow-packed. Cows had ad libitum access to water in two 1,136-liter stock tanks (Rubbermaid Commercial Products LLC, Winchester, VA) at all times.

Energy, crude protein (**CP**), vitamins, and minerals required for maintenance and gestation were determined for Exp. 1 and 2 before experiments started based on cow breed and body weight (**BW**; NRC, 2000) and hay supply. A 5-yr-old, 612-kg Angus cow at a body condition score 5 (250 d in gestation) previously exposed to 7.5 °C average temperature was used as a model to calculate nutrients required for maintenance and gestation. An initial estimate of DMI required was based on brome hay containing 56% total digestible nutrients and 10.5% CP. This resulted in a hay intake requirement of 11.6 kg DM, but it projected a daily energy deficit of 0.48 Mcal net energy for maintenance (**NE_m**)/cow. Daily NE_m deficit projected was ignored in this experiment due to the short term of the experiment and its objective.

Deliveries of hay, after weighing (XR 3000 Tru-Test Scale, Tru-Test Inc., Mineral Wells, TX) and accounting for expected intake (11.6 kg DM/cow) and 12% waste (1.4 kg DM/cow), were made daily (processed hay: P-BUNK and P-SRFC) at 0800 h or after visual appraisal of the amount of hay left at the feeding site (U-RING and U-ROLL). Hay was not delivered to U-RING or U-ROLL if hay remaining at feeding site was projected to last over 12 h. Generally, deliveries of unprocessed hay (26 kg DM/cow) occurred every other day. Delivery time and amount were recorded at the time of delivery.

A single hay lot, harvested as large round bales (1.5 m diameter × 1.2 m width) from the same field, was fed across periods (Table 2). Individual round bales were sampled for nutrient analyses by collecting 15 cores per bale using a 1.5 cm diameter × 61 cm length Forageurs Hay Probe (Forageurs Corp.; Lakeville, MN) from the twine or round side of the bale before delivery; subsequently, the twine was removed before delivery or processing.

Figure 1. Round bale feeders used in all experiments for ad libitum hay access (a) and in Exp. 3 for time-controlled hay access (b).

Table 2. Mean nutrient concentration of grass hay, wet beet pulp, and dry corn screenings (dry matter basis) and guaranteed analyses (as-is) of mineral supplement for each experiment

	Hay for experiment[1]			Supplement			
Nutrient	1	2	3	Mineral (Exp. 1, 2)	Mineral (Exp. 3)	Wet beet pulp (BP)	Dry corn screenings (CS)
DM, %	89.0	89.6	90.0	96.9	—	26.6	89.8
CP, %	10.4	10.0	8.8	9.7	—	7.4	6.8
ADF, %	36.8	37.0	46.4	0.01	—	34.7	3.4
NDF, %	58.3	59.1	68.1	0.7	—	53.5	10.9
Ash, %	6.3	6.3	7.5	29.4	—	17.3	2.2
TDN, %	63.8	63.7	52.1	81.4	—	64.7	86.9
NE_m, Mcal/kg	1.43	1.43	1.04	1.98		1.46	2.14
Ca, %	—	—	—	5.0	13.0	—	—
P, %	—	—	—	3.5	6.0	—	—
Mg, % max	—	—	—	1.5	1.5	—	—
K, % min	—	—	—	4.0	1.5	—	—
Zn, ppm	—	—	—	3,750	3,600	—	—
Mn, ppm	—	—	—	1,250	3,600	—	—
Cu, ppm	—	—	—	1,250	1,200	—	—
Co, ppm	—	—	—	30	12	—	—
I, ppm	—	—	—	68	60	—	—
Se, ppm	—	—	—	13	27	—	—
Vitamin A, IU/kg	—	—	—	36,287	136,078	—	—
Vitamin D3, IU/kg	—	—	—	9,072	13,608	—	—
Vitamin E, IU/kg	—	—	—	45	136	—	—
NaCl, %	—	—	—	—	25	—	—

[1] Average nutrient concentration across experimental periods.

Hay samples were then frozen for further analyses. Nutrient concentrations of hay and mineral supplement are listed in Table 2.

Prior to hay delivery, subsequent to the first delivery, hay waste (left on the pen surface or in the structure where it was delivered) was estimated based on weighing and sampling an area corresponding to 2% of the total waste area. The overall waste area was measured and sufficient random subsamples of the area were obtained using a 0.093-m^2 metal quadrat to represent 2% of the total waste area. Hay waste area varied by treatment because of feeder type or delivery site. Hay waste areas measured on average 149, 223, 70, and 223 m^2, respectively, for U-RING, U-ROLL, P-BUNK and P-SRFC treatments. Therefore, approximately 33, 49, 16, and 49 hay waste subsamples were collected from sampling areas totaling 3.0, 4.5, 1.4, and 4.5 m^2, respectively, from U-RING, U-ROLL, P-BUNK, and P-SRFC treatments each period. Total fresh waste was extrapolated from weight of subsamples representing waste area by dividing total subsample waste by 2%; waste samples were frozen for further analysis. DMI was determined during each feed delivery and waste sampling event (daily for processed hay; every other day for unprocessed hay), within period, by subtracting waste amount (waste as-is extrapolated from sub-sample waste × DM content of waste subsamples) from delivered hay DM (delivered hay weight as-is × DM content of hay delivered). Prorated individual daily dry matter intake (expressed as mass and as a proportion of the period BW) and waste (expressed as mass and as a percentage of measured DMI) were dependent variables. In these experiments, sum of daily feed intake and waste represents total amount of hay disappearance or amount of hay required in inventory.

Cows had ad libitum access to a 102-kg protein, vitamin, and mineral supplement tub (Purina Mills Wind & Rain All Season 4 Mineral Tub, Purina Mills LLC, St. Louis, MO) with a manufacturer rating of 1 tub per 25 to 30 hd to ensure that cows met their needs for these nutrients (Table 2). Each treatment group had free-choice access to a 22.7-kg white-salt block (Champion Choice White Salt Block, Cargill Salt, Minneapolis, MN). Mineral tubs were weighed (XR 3000 Tru-Test Scale, Tru-Test Inc., Mineral Wells, TX) at the start and end of each 10-d period. Concurrently, samples of mineral from tubs were collected for DM determination. Mineral DM intake was determined by subtracting weight of mineral DM remaining in tub from that present at delivery. Prorated daily individual mineral DM intake was a dependent variable.

Experiment 2. Experiment 2 was designed as a 6 × 6 Latin Square utilizing 54 multiparous, late-gestating, Angus cows (616 kg initial BW) to study effects of supplement moisture content and feeding method on hay and energy supplement intake and waste. Cows (*n* = 9 cows/group) were stratified by age and BW into six groups (group = experimental unit). At the start of the first of six 10-d treatment periods, groups were randomly assigned to one of six pens containing an energy supplement (corn screenings, **CS**, or wet beet pulp, **BP**) and delivery treatment (CS or BP in a bunk or tire, or BP only on the pen surface) combination. Subsequent group allocation to pens followed a previously randomly selected 6 × 6 Latin Square design. Cows weight was obtained (XR 3000 Tru-Test Scale, Tru-Test Inc., Mineral Wells, TX) after removing feed for 12 h (to minimize effects of gut fill) at the beginning and end of each 10-d period. Treatments consisted of feeding no energy supplement (**CTRL**), feeding CS in a bunk **(CS-BUNK)** or in an inverted tire (**CS-TIRE**), or feeding BP in a bunk (**BP-BUNK**), tire (**BP-TIRE**), or on the pen surface (**BP-SRFC**). Bunks measured 0.91 m width × 4.88 m length × 0.76 m height at feeding surface. Inverted tires simply prevented supplement delivery to be contained within an area which measured 1.5 m^2 (1.38 m diameter × 0.71 m wall height). Surface area on which BP was delivered measured 3.7 m × 1.2 m.

Hay, in large round bales (1.5 m diameter × 1.2 m width), was delivered in hay rings (Figure 1a) made of polyethylene pipe (2.44 m diameter × 1.22 m height with 4 rings and 6 legs; Century Livestock Feeders Inc., Shidler, OK) in each pen. Pens were laid out using electric fencing on frozen, snow-covered pastures (undisturbed snow depth: 28 cm; Table 1). Each pen measured 39.6 m × 100.6 m resulting in stocking rates of 443 m^2/cow. Because of temperatures prevailing during the experiment (Table 1), pen surfaces remained frozen and snow-packed. Cows had ad libitum access to water in two 1,136-liter stock tanks (Rubbermaid Commercial Products LLC, Winchester, VA) at all times.

As for Exp. 1, energy, CP, vitamins, and minerals required for maintenance and gestation were determined prior to the experiment based on a 5-yr-old, 612-kg Angus cow at a body condition score 5 (250 d in gestation) previously exposed to 7.5 °C average temperature. Supplementation with BP or CS was intended to replace hay intake sufficiently to cover the daily energy deficit (0.48 Mcal NE_m/cow) within the projected 11.6 kg DMI/cow predicted by this procedure. Supplement deliveries were designed to account for DM necessary to cover energy deficit (1.7 kg BP/cow and 0.5 kg CS/cow) and waste projected according to the worst-case scenario: 50% expected from BP delivered on the pen surface.

Because of the un-supplemented control group, hay delivery amounts were unadjusted for energy supplementation. Deliveries of hay, after weighing (XR 3000 Tru-Test Scale, Tru-Test Inc., Mineral Wells, TX) and accounting for expected intake (11.6 kg DM/cow) and waste, were made after visual appraisal of hay left at the feeding site. Hay was not delivered if hay remaining at feeding site was projected to last over 12 h. Downward adjustments in hay deliveries occurred in BP-BUNK and BP-TIRE treatments early in each period as it was evident cows in these treatments consumed less hay. Generally, hay deliveries occurred every other day. Delivery time and amount were recorded at the time of delivery.

A single hay lot, harvested as large round bales (1.5 m diameter × 1.2 m width) from the same field, was fed across periods (Table 2). Wet beet pulp was procured from a sugar beet processing plant located 260 km from the study site in a single semi-trailer load (approximate net weight: 20,000 kg) and stored for the duration of the experiment in a concrete block-sided bay on packed snow. Corn screenings were purchased locally in a single semi-trailer load (approximate net weight: 20,000 kg) and stored for the duration of the experiment in an indoor grain bin.

Individual round bales were sampled for nutrient analyses following the same procedures as for Exp. 1. Supplement samples were collected for analyses at the start of every period by collecting five random grab samples. Hay and supplement samples were then frozen for further analyses. Nutrient concentrations of hay and energy and mineral supplements are listed in Table 2.

Frequency and delivery of hay and determination of hay intake and waste occurred according to procedures outlined for Exp. 1. In this experiment, hay waste area surrounded each hay ring measured on average 149 m^2. Hay waste sub-samples (*n* = 33) were collected from sampling 3 m^2 each period. Supplement waste was measured once at the end of each 10-d period based on the same procedure as for hay waste. Yet, CS delivered, regardless of delivery site, was consumed completely. Waste collection areas from BP feeding sites averaged 72, 110, and 89 m^2, respectively, for BP-SRFC, BP-BUNK, and BP-TIRE treatments. This resulted in collection of 16, 24, and 20 BP waste subsamples from 1.4, 2.2, and 1.8 m^2, respectively, from BP-SRFC, BP-BUNK, and BP-TIRE feeding sites. Dry matter intake of energy supplement was determined by subtracting waste amount (waste as-is extrapolated from sub-sample waste × DM content of supplement waste subsamples) from delivered supplement DM (delivered supplement weight as-is × DM content of supplement delivered). Prorated individual daily energy supplement dry matter intake (expressed as mass) and waste (expressed as mass and as a percentage of measured DMI) were dependent variables. The sum of daily supplement intake and waste represents total amount of supplement disappearance or amount of supplement required in inventory.

Cows had access to a 102-kg protein, vitamin, and mineral supplement tub (Purina Mills Wind & Rain All Season 4 Mineral Tub, Purina Mills LLC, St. Louis, MO) with a manufacturer rating of 1 tub per pen 25 to 30 hd to ensure that cows met their needs of these nutrients (Table 2). Each treatment group had free-choice access to a 22.7-kg white-salt block (Champion Choice White Salt Block, Cargill Salt, Minneapolis, MN). Mineral tubs were weighed (XR 3000 Tru-Test Scale, Tru-Test Inc., Mineral Wells, TX) at the start and end of each 10-d period, and mineral intake determination was conducted according to the same procedures as those outlined for Exp. 1.

Experiment 3. Experiment 3 was designed as a 3 × 3 Latin Square utilizing 24 multiparous, late-gestating, Angus cows (584 kg initial BW) to study effects of access time to hay on hay intake and waste. Cows (n = 8 cows/group) were stratified by age and BW into three groups (group = experimental unit). At the start of the first of three 10-d treatment periods, groups were randomly assigned to one of three pens containing a hay access-time treatment. Subsequent group allocation to pens followed a previously randomly selected 3 × 3 Latin Square design replicated in time. Cows weight was obtained (XR 3000 Tru-Test Scale, Tru-Test Inc., Mineral Wells, TX) after removing feed for 12 h (to minimize effects of gut fill) at the beginning and end of each 10-d period. Treatments consisted of permitting daily access time to round-bale hay feeders for 6, 14, or 24 h. Restricted access (6 or 14 h/d) was accomplished using metal round-bale feeders (2.44 m diameter × 1.27 m height) equipped with a stanchion-blocking curtain (Figure 1b) controlled by timers (E-Z Hay Feeder, Priest River, ID). Otherwise, hay rings (Figure 1a) were made of polyethylene pipe 2.44 m diameter × 1.22 m height with 4 rings and 6 legs (Century Livestock Feeders Inc., Shidler, OK). This experiment was conducted in the late spring; experimental conditions are listed in Table 1. Each concrete-surfaced pen measured 14.6 m × 27.7 m resulting in stocking rates of 50 m^2/cow; a metal roof covered 130 m^2 (16.2 m^2/cow) at the north end. Cows had ad-libitum access to a single WaterMatic 300 Series water trough (Ritchie Industries Inc., Conrad, IA).

Energy, crude protein (CP), vitamins, and minerals required for maintenance and gestation were determined based on a gestating (250 d) 5-yr-old Angus cow weighing 612 kg (NRC, 2000) with a BCS of 5 previously exposed to thermoneutral conditions. Projected DMI for cows in this experiment was 11.1 kg/cow with no energy deficit.

Deliveries of hay, after weighing (XR 3000 Tru-Test Scale, Tru-Test Inc., Mineral Wells, TX) and accounting for expected intake (11.1 kg DM/cow) and waste, were made after visual appraisal of hay left at the feeding site. Greater waste was expected for cows with 24-h access to hay in this experiment because of denser cow stocking rate. Hay was not delivered if hay remaining at feeding site was projected to last over 12 h. Generally, hay deliveries at the 24-h access site occurred every other day those at the restricted access sites occurred every 72 h or longer. Delivery time and amount were recorded at the time of delivery.

A single hay lot, harvested as large round bales (1.5 m diameter × 1.2 m width) from the same field, was fed across periods (Table 2). Individual round bales were sampled for nutrient analyses following the same procedures as for Exp. 1. Frequency and delivery of hay and determination of hay intake and waste occurred according to procedures outlined for Exp. 1. In this experiment, hay waste area surrounded each hay ring measured on average 149 m^2. Hay waste sub-samples (n = 33) were collected from sampling 3 m^2 each period. Cows had free-choice access to a loose complete vitamin and mineral source (Rangeland Year Round 6 Mineral Complete Altosid, Land O' Lakes Purina Feed LLC, Shoreview, MN) in a 60 cm × 60 cm × 30 cm custom-built feeder to meet their mineral needs (Table 2). Loose complete vitamins and minerals were mixed at 50:50 ratio with granulated white-salt (Champion Choice White Salt, Cargill Salt, Minneapolis, MN). No effort was made in this experiment to measure mineral consumption.

Sample Processing and Analyses

Subsamples of feed waste or samples of hay and supplements were thawed and then dried in a 60 °C forced-air oven for 72 h (Model DC-246E, GS Blue M Electric, Watertown, WI) for DM determination. Manure was separated from feeds once waste subsamples were dried. After moisture removal was completed, all hay and supplement samples were ground in a Wiley mill (Model 4, Tomas-Wiley Laboratory Mill, Thomas Scientific, Swedesboro, NJ) using a 1-mm screen. All samples were then analyzed at a commercial forage analysis lab using wet chemistry analysis to obtain CP, acid detergent fiber (**ADF**), and neutral detergent fiber (**NDF**), and ash (Dairyland Laboratories, Arcadia, WI). Crude protein, NDF, ADF, and ash were measured using AOAC Official Method 990.03, AOAC Official Methods 2002.04 (2005), AOAC Official Method 973.18 (1996), and AOAC Official Method 942.05 (1996), respectively.

Statistical Analyses

Statistical analyses were completed by using Proc Mixed of SAS (version 9.4; SAS Institute Inc., Cary, NC). Data from Exp. 1 were analyzed as a 4 × 4 Latin Square design. Data from Exp. 2 were analyzed as a 6 × 6 Latin square design. Data from Exp. 3 were analyzed as 3 × 3 Latin square design replicated twice. Preplanned contrast coefficients were coded in a contrast statement in Proc Mixed to understand two effects on dependent variables: 1) hay access restriction (24-h vs. 6- and 14-h access) and 2) extent of hay restriction (6-h vs. 14-h access) in Exp. 3. Cow group was the experimental unit. Body weight was used as a covariate and retained in the model if its effect on the dependent variable was $P < 0.10$. Effects were considered significant at $P < 0.05$; differences with P-values between 0.05 and 0.10 were discussed as trends.

RESULTS AND DISCUSSION

Experiment 1

Feeding unprocessed hay in a ring or rolled out on the pen surface, processed hay in a bunk or on the pen surface had no effect ($P \geq 0.579$) on hay DMI expressed as mass or percentage of BW (Table 3). Total DMI averaged 2% of cow BW. Similarly, Buskirk et al. (2003) and Moore and Sexten (2015) reported that daily hay intake was not affected by hay feeder type.

Estimates of hay waste in Exp. 1 were similar to those observed previously when delivering unprocessed hay in a hay feeder (Buskirk et al., 2003; Martinson et al., 2012; Moore and Sexten, 2015) or delivering processed or unprocessed hay on the pen surface (Lechtenberg et al., 1974; Blasi et al., 1993; Volesky et al., 2002).

Compared with unprocessed hay fed in a ring or processed hay feed in a bunk, hay waste, expressed as mass or percentage, was greatest ($P \leq 0.007$) when it was delivered on the pen surface whether it was processed or not (Table 3). Similarly, cows fed hay in tapered-cone round-bale feeders required less hay (hay intake and waste) than cows fed hay on the pen surface processed or not (Landblom et al., 2007). Extrapolation of effects of delivering hay, processed or not, on the pen surface on waste observed in this experiment and that of Landblom et al. (2007) require further consideration. Published evidence exists of an effect of forage source on hay waste. Moore and Sexten (2015) described a forage type (alfalfa or tall fescue) × hay–feeder type interaction. Similarly, hay waste was unchanged for cows fed processed hybrid Sudan hay in a bunk or unrolled on the pen surface, but hay waste was greatest for cows fed wheat hay unrolled on the pen surface (Blasi et al., 1993).

Feed inventory required when feeding processed hay in a feed bunk or unprocessed hay in a ring feeder would need to be 2.5% and 6.9% greater, respectively, than expected daily DMI. On the other hand, feed inventory required when delivering processed or unprocessed hay on the pen surface would need to be about 18.2% and 19.6% greater, respectively, than expected daily DMI.

Cows fed unprocessed hay in a ring consumed on average 0.31 kg less ($P \leq 0.014$) mineral supplement daily than cows fed hay in all other treatments (Table 3). Mineral supplement consumption by cows fed hay in a ring reported herein was similar to that previously reported for 400-kg yearling steers or beef cows weighing between 562 and 579 kg (Aubel et al., 2011; Yelich et al., 2019). No single plausible explanation exists for what factors led to greater intake of mineral supplement by cows in P-BUNK, P-SRFC, or U-SRFC. Although one might propose that in the absence of a feeder, as in U-ROLL and P-SRFC treatments, trampled feed may drive cows to spend more time at the mineral supplement feeder in search of "clean" feed, this would not explain why cows fed P-BUNK consumed 0.33 kg more mineral/cow daily than those fed U-RING. Linear dimension of P-BUNK was actually larger than that of U-RING; therefore,

Table 3. Hay, mineral supplement and total dry matter intake and hay waste (Experiment 1) by cows fed whole hay in a ring (U-RING) or rolled on the pen surface (U-ROLL) or processed hay fed in a bunk (P-BUNK) or on the pen surface (P-SRFC)

Item	U-RING	U-ROLL	P-BUNK	P-SRFC	SE	*P*-value
Group, *n*	4	4	4	4		
Cow BW, kg	609	615	604	606	5.45	0.076
Hay						
Intake, kg/d	11.84	11.88	11.88	10.77	0.70	0.595
Intake, % BW	1.94	1.93	1.97	1.78	0.11	0.579
Waste, kg/d	0.78^a	2.17^b	0.28^a	1.81^b	0.24	0.002
Waste, %[1]	6.92^a	19.64^b	2.54^a	18.23^b	2.81	0.007
Mineral supplement						
Intake, kg/d	0.40^a	0.62^b	0.77^b	0.76^b	0.05	0.012
Total						
Intake, kg/d	12.24	12.54	12.62	11.51	0.73	0.675
Intake, % BW	2.00	2.03	2.09	1.90	0.12	0.655

[1] Waste expressed as a proportion of intake.

[a,b] Within a row, least square means without common superscripts differ ($P < 0.05$).

the difference in mineral intake likely did not result from competition at the hay-feeding site. Although researchers have published abundantly on effects of season, forage supply, and form of mineral supplement on mineral intake, there appear to be no references to effects of forage feeder type or delivery site on mineral supplement consumption.

Experiment 2

Feeding cows no energy supplement or CS in a feed bunk or tire led to the greatest ($P \leq 0.011$) hay intake expressed as mass or percentage (Table 4). Feeding cows CS in a tire or BP on the pen surface led to intermediate hay intake, which was greater ($P \leq 0.05$) than that by cows fed BP delivered in a bunk. Walker et al. (2013), in two studies, reported no difference in hay intake by cows in their last trimester of gestation fed bermudagrass hay ad libitum and supplemented with liquid protein through a lick tank or applied to the round bale or fed dried distillers grains daily (**DDGS**).

Hay or energy supplement waste differed based on supplement type and feeding method (Table 4). Supplementing cows with CS led to no energy supplement waste. Hay waste was greatest ($P \leq 0.003$) when BP was placed in a bunk; yet, energy supplement waste was greatest ($P < 0.0001$) when BP was placed on the pen surface. Feeding BP in a tire resulted in the lowest ($P \leq 0.024$) hay waste, which was similar to that from CTRL cows; energy supplement waste by cows fed BP-TIRE was similar ($P = 0.781$) to that from BP-BUNK but tended to differ from that of cows fed CS-TIRE ($P \leq 0.078$) and CS-BUNK ($P = 0.076$). Similarly, hay waste was intermediate for cows supplemented with DDGS, greatest for cows fed a liquid supplement free choice, and lowest for cows fed liquid-supplement-treated hay bales (Walker et al., 2013). In a subsequent experiment, Walker et al. (2013) reported that hay waste was greater for cows fed a liquid protein supplement in a lick tank with access to bermudagrass hay than for those fed the same supplement poured into hay bales.

No obvious explanation exists for why cows consuming BP supplement from a bunk wasted more hay than those consuming BP supplement from a tire, while there were no differences in hay waste between cows consuming CS from a bunk or tire. One is left to speculate whether inherent differences in eating rate between BP and CS affected time spent at the energy supplement-feeding site. At the same maturity, grass (species unspecified), dried for 5 h to reach 30% DM, was consumed more rapidly by dairy cows than grass left at cutting moisture content (21.8% DM; Cabrera Estrada et al., 2004). In the present experiment, when cows were consuming CS, its inherently faster eating rate had little effect on time spent at the energy supplement-feeding site. Therefore, interactions among cows at the hay-feeding site were probably unaffected by time spent at the energy supplement-feeding site. In contrast, it is likely that the inherently slower eating rate of BP was further slowed by feeding it on a bunk with an elevated eating surface but not in a tire where cows could eat in a grazing posture. Dairy cows eating with their heads down produce more saliva than those eating with their heads

Table 4. Hay, energy, and mineral supplement and total dry matter intake and hay and energy supplement waste by cows (Experiment 2) receiving beet pulp (BP) or corn screenings (CS) or no energy supplement (CTRL) delivered in bunks, tires, or the pen surface

Item	CTRL	BP-BUNK	BP-TIRE	BP-SRFC	CS-BUNK	CS-TIRE	SE
Group, *n*	6	6	6	6	6	6	
Cow BW, kg	644	640	640	645	644	643	5.71
Hay							
Intake, kg/d	13.15^{e}	10.39^{a}	10.94^{ab}	11.58^{bc}	12.96^{de}	11.97^{cd}	0.35
Intake, % BW	2.04^{e}	1.62^{a}	1.70^{ab}	1.80^{bc}	2.01^{de}	1.86^{cd}	0.05
Waste, kg/d	1.30^{ab}	1.84^{c}	1.12^{a}	1.35^{b}	1.46^{b}	1.42^{b}	0.13
Waste, % [2]	9.81^{ab}	17.96^{c}	10.40^{ab}	11.66^{ab}	11.17^{ab}	12.05^{b}	1.17
Supplement							
Intake, kg/d	0.00^{a}	3.62^{d}	3.61^{d}	3.00^{c}	1.29^{b}	1.29^{b}	0.08
Waste, kg/d	0.00^{a}	0.07^{a}	0.09^{a}	0.66^{b}	0.00^{a}	0.00^{a}	0.03
Waste, %[1]	0.00^{a}	2.06^{a}	2.31^{a}	21.85^{b}	0.00^{a}	0.00^{a}	1.07
Mineral supplement							
Intake, kg/d	0.45^{c}	0.33^{a}	0.40^{abc}	0.41^{bc}	0.34^{ab}	0.36^{ab}	0.06
Total							
Intake, kg/d	13.59	14.35	14.96	15.01	14.58	13.60	0.39
Intake, % BW	2.12	2.23	2.32	2.33	2.27	2.11	0.06
NE_m, Mcal/d	19.69	20.81	21.71	21.79	21.95	20.60	0.56

[1] Waste expressed as a proportion of hay or supplement intake.

[a,b,c,d,e] Within a row, least square means without common superscript letters differ ($P < 0.05$).

nearly horizontal (Albright, 1993). This may have created greater disturbances at both the hay and energy supplement-feeding site for BP-BUNK but not for BP-TIRE, which resulted in greater hay trampling and waste.

Mineral supplement intake was less ($P \leq 0.041$) for cows fed BP or CS in a bunk and CS in a tire than for those fed no energy supplement (Table 4). Consumption of mineral by cows fed CTRL was similar ($P \geq 0.125$) to that by cows fed BP-TIRE or BP-SRFC. Mineral supplement intake was not different ($P \geq 0.193$) among cows fed BP-TIRE, BP-SRFC, or CS-TIRE. In this experiment, mineral intakes measured across treatments were similar to those observed previously for yearling steers and beef cows (Aubel et al., 2011; Yelich et al., 2019). Differences in mineral intake between cows supplemented with energy and those not supplemented may result from cows fed no energy supplement spending more time at the mineral feeder.

Independent of supplement type or feeding method, total DMI did not differ across all treatments (model *F*-test $P = 0.054$). This suggests that cows reached a set daily DMI regardless of amount or type of energy supplement. Braungardt et al. (2010) reported similar total DMI for cows permitted ad-libitum access to alfalfa-grass hay and those fed corn stalks supplemented with DDGS or corn bran. Furthermore, although cows fed no energy supplement consumed the same total amount of DM, greater hay and mineral intake by cows fed no energy supplement made up for total NE_m intake differences resulting from the absence of energy supplementation (Table 4; NE_m intake model *F*-test $P = 0.068$). This observation may help explain why cows fed no energy supplement consumed more mineral supplement. There is evidence of increased mineral consumption resulting from restricted intake. Consumption of loose mineral supplement by cows fed at 50% or 75% of ad libitum was greater than that by cows fed ad libitum (Fisher et al., 1972).

Experiment 3

Cows allowed access to hay rings for 24 h consumed and wasted more hay ($P < 0.0001$) than those given 6- or 14-h access (Table 5), and cows allowed 6-h access consumed and wasted less than those allowed 14-h access ($P < 0.0001$). Heifers allowed 24-h hay access consumed 10.9% more hay than those restricted to 8-h access (Sexten and Davis, 2010). Limited access time to the hay feeder resulted in reduced hay waste probably because cows were less able to spend time sorting through hay.

Average BW was not affected by access time to hay feeders ($P \geq 0.870$); therefore, on all treatments, the energy consumed from hay was sufficient to maintain BW and fetal growth (NRC, 2000).

Table 5. Hay dry matter intake and waste by cows given access to hay in feeder rings for 6, 14, or 24 hour (Experiment 3)

	Access to hay rings, h				Contrast *P*-values	
Item	6	14	24	SE	6- and 14-h access vs. 24-h access	6- vs. 14-h access
Group, *n*	6	6	6			
Cow BW, kg	601	603	603		0.870	0.872
Intake, kg/d	9.60	11.06	12.42	0.12	<0.001	<0.001
Intake, % BW	1.59	1.84	2.06	0.02	<0.001	<0.001
Waste, kg/d	0.08	0.47	0.95	0.05	<0.001	<0.001
Waste, %[1]	0.82	4.23	7.67	0.41	<0.001	<0.001

[1] Waste expressed as a proportion of intake.

Assuming that 11.43 Mcal NE_m/d (9.47 Mcal for maintenance + 1.96 Mcal for fetal growth) was required for these functions by cows weighing 600 kg, then cows in each of these treatments consumed 102, 91, and 79 g DM/kg $BW^{0.75}$ for maintenance and fetal growth. These values reflect NE_m concentrations achieved when cows consumed feed for 24 h (ad libitum) or for 14 or 6 h of 0.92, 1.03, or 1.19 Mcal/kg DM, respectively (NE_m expressed as kcal/kg $BW^{0.75}$divided by g DM/kg $BW^{0.75}$). Corresponding metabolizable energy (**ME**) concentrations were 1.76, 1.87, and 2.04 Mcal/kg DM. The expected ME concentration based on chemical analyses of hay fed to these cows was 1.88 Mcal/kg DM. Therefore, cows given 14-h access to hay feeders achieved the expected dietary ME of hay.

Cattle limit-fed a high-energy diet had greater dietary DM digestibility (Klinger et al., 2007) than those fed a high-forage diet ad libitum. In the present experiment, digestible energy (**DE**) concentration derived from ME reflected the finding that cows given access for 14-h digested hay at expected values, whereas those fed for ad libitum access had 6.1% less DE. Cows given access to hay for 6 h had 9.4% greater DE. The fact that feeding hay for 6 h did not result in loss of BW, through increased forage digestibility and reduced overall hay waste would suggest there is an opportunity for operators to reduce feeding cost by limiting access time to hay. Yet, operators must monitor forage quality and cow body condition to insure they meet daily nutrient requirements.

APPLICATIONS

When forage and grain prices are high, cow-calf operators should focus management efforts to preserve feed resources. During feeding, hay DM waste ranges from a minimum of 5% when hay-ring feeders are used to as much as 10% to 18% when high-moisture energy supplements are fed. Achieving zero waste is impossible, but waste values from the current and other experiments using feeders place 5% waste as an achievable goal; using no hay feeder consistently leads to 20% hay waste. At current hay prices ($125/metric ton DM) and projected needs for a cow fed hay for 210 d (2.7 metric tons DM), the value of differential loss between 20% and 5% losses is $50.62/cow or $5,062 in a 100-cow herd annually.

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