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Evaluation of growth performance, carcass characteristics, and methane and CO_2 emissions of growing and finishing cattle raised in extensive or partial-intensive cow-calf production systems

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ABSTRACT

An experiment was conducted over 2 yr to measure performance and greenhouse gas (GHG) emissions of weaned calves from two cow-calf production systems. Crossbred steers and heifers (*n* = 270, initial body weight (BW) = 207 kg, SD = 35) were used in a randomized complete block design, with treatments applied to the cow-calf system. Treatments were: 1) a traditional system consisting of April to June calving with smooth bromegrass pasture and grazed corn residue as forage resources (TRAD); 2) an alternative system consisting of July to September calving utilizing partial-drylot feeding, summer-planted oats, and corn residue grazing (ALT). Calves from both production systems were weaned at the same age and grown (diet NEg = 1.05 Mcal kg^{-1}) for approximately 117 d. The calves then transitioned to a high-grain finishing diet (year 1: NEg = 1.32 Mcal kg^{-1}; year 2: NEg = 1.39 Mcal kg^{-1}) and fed to a targeted 1.52 cm backfat. Growth performance in the grower phase resulted in greater ($P < 0.01$) average daily gain (1.39 vs. 1.22 ± 0.02 kg), greater gain:feed ($P < 0.01$; 0.157 vs. 0.137 ± 0.003) for ALT calves compared to TRAD calves, However, a lower initial BW ($P < 0.01$; 185 vs. 229 ± 4.9 kg) resulted in a lower ending BW ($P < 0.01$; 347 vs. 371 ± 2.9 kg) for ALT calves compared to TRAD calves in spite of improved growth performance. In the finisher phase, ALT calves gained less (1.52 vs. 1.81 ± 0.218 kg; $P = 0.02$), were less efficient (0.139 vs. 173 ± 0.0151; $P = 0.01$) but exhibited similar hot carcass weights (HCW) (388 vs. 381 ± 3.8 kg; $P = 0.14$) compared to TRAD calves. Each pen of calves was put into a large pen-scale chamber that continuously measured carbon dioxide (CO_2) and methane (CH_4) for 5 d during the grower and finisher phases. The average CH_4 and CO_2 production per unit of feed intake was used to calculate total GHG emissions over the entire grower and finisher phase. Overall, there were no differences ($P \geq 0.17$) between treatments for CH_4 per day and per kilogram dry matter intake (DMI). However, ALT calves tended to produce less ($P \leq 0.10$) CO_2 per day and per kilogram DMI than TRAD calves. Overall, methane emissions were greater in ALT calves (110.7 vs. 92.2 ± 8.3 g CH_4 kg^{-1} HCW; $P = 0.04$) than TRAD calves. The ALT calves required 27 additional days on feed to market, which resulted in more total CH_4 per animal across the entire feeding period ($P = 0.02$) than TRAD calves. Production systems that reduce days to market to achieve similar HCW may reduce GHG emissions.

Lay Summary

There are many reasons (i.e. drought, limited perennial forage, calving) for using intensive or partially intensive production practices (e.g. drylotting or confinement) in a cow-calf enterprise. These practices may impact subsequent calf growth and feedlot performance. In addition, limited data are available comparing the environmental impacts (i.e., greenhouse gas (GHG) emissions) from different cow-calf production systems. This experiment evaluated the effects of a partial-intensive cow-calf production system on post-weaning calf growth performance, carcass characteristics, and GHG emissions. Calves from the partial-intensive cow-calf system had improved growth compared to calves from the extensive cow-calf system during the grower phase. During finishing, calves from the partial-intensive cow-calf system had poorer growth performance resulting in calves from the partial-intensive cow-calf system requiring an additional 27 d on feed to reach finish as calves from the traditional cow-calf system. These differences are likely due to compensation from lower gain periods resulting in better gain in the subsequent growth period. Cow-calf production system did not alter methane and carbon dioxide emissions per kilogram of intake. However, because calves in the partial-intensive cow-calf system required additional days on feed, absolute methane and carbon dioxide emissions were greater per animal for the partial-intensive cow-calf system compared to the extensive cow-calf system suggesting that reducing days to market may reduce emissions from beef systems.

Key words: beef cattle, carbon dioxide, methane, emissions, growing, finishing

Abbreviations: ADG, average daily gain; ALT, alternative cow-calf system; BW, body weight; CH_4, enteric methane; CO_2, carbon dioxide; DM, dry matter; DMI, dry matter intake; DRC, dry-rolled corn; G:F, gain to feed ratio; GHG, greenhouse gases; GH, grass hay; HMC, high-moisture corn; MDGS, modified distillers grains plus solubles; TRAD, traditional cow-calf system

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Introduction

The beef livestock sector is often scrutinized due to the perceived excessive emissions of greenhouse gases (GHG), particularly enteric methane (CH_4), which has been correlated with rising ambient temperatures and climate change (Valone, 2021). In the United States, livestock production is thought to be responsible for 3.8% of all GHG emissions, primarily from enteric CH_4 and nitrous oxide emissions (EPA, 2021).

Diets containing high concentrations (>40%) of forage result in greater CH_4 emissions per kilogram of intake, per calorie of energy intake, and kilogram of gain or production, but not necessarily animal^{-1} d^{-1}(Winders et al., 2020). Carbon dioxide is also naturally produced by cattle during respiration. While not as potent as CH_4, a greater understanding of CO_2 emissions is important when quantifying the total GHG emissions of beef systems. Often CO_2 emissions are ignored in GHG budgeting as respiration is considered biogenic carbon naturally recycled (IPCC, 2006). Although GHG emissions by cattle consuming diets of various quality has been measured and summarized (Beauchemin et al., 2008; NASEM, 2016), there are no direct known comparisons of GHG emissions of cattle with similar genetics produced in separate beef systems.

Intensive cow-calf systems utilizing drylot and total-mixed rations have been compared to traditional, extensive cow-calf systems with varying results through weaning (Deutscher and Slyter, 1978; Perry et al., 1974; Loerch, 1996; Anderson et al., 2013; Burson 2017) backgrounding (Neira et al., 2019), and feedlot phases (Deutscher and Slyter, 1978; Cole, 2015; Gardine et al., 2019). However, limited data exists investigating subsequent finishing performance and carcass characteristics.

Our objective was to measure post-weaning growth performance through the grower and finisher phases, carcass characteristics, and GHG emissions from calves raised in different beef systems when consuming a high-forage growing diet or a high-concentrate finishing diet. It was hypothesized that post-weaning calf growth performance, carcass characteristics, and methane and carbon dioxide emissions would not differ from calves raised in a partial-intensive or extensive cow-calf production system.

Materials and Methods

Facilities and management procedures used in this experiment were approved by the University of Nebraska–Lincoln Institutional Animal Care and Use Committee (IACUC # 1491 & 1785). This experiment was conducted over 2 yr at the Eastern Nebraska Research and Extension Center (ENREC) near Mead, Nebraska. The animals and treatments utilized in the current experiment originated from the experiment by Carlson et al. (2022) that describes the two cow-calf systems in detail. Briefly, Carlson et al. (2022) utilized multiparous, crossbred beef cows (n = 160; average age = 6.2 ± 2.8 yr old) in a randomized complete block experimental design. Cows originated from two separate herds maintained at ENREC. Bulls originated from the same herd as one of the sources of cows. The same set of Simmental × Angus bulls were used for both years of the experiment. Treatments included: 1) a traditional system with April to May calving, utilizing smooth bromegrass (*Bromus inermis*) based pastures and corn residue grazing (TRAD), or 2) an alternative system with July to August calving, utilizing confined feeding in the spring and summer, fall grazing of late summer-planted oats (*Avena sativa*, var. *goliath*), and corn residue grazing in the winter (ALT). Calves from Carlson et al. (2022) were utilized in the current experiment following weaning. Over 2 yr, crossbred steers and heifers (n = 270, initial body weight (BW) = 207 kg, SD = 35) were utilized in a randomized complete block experimental design, with the experimental treatments applied during the previous cow-calf system. Experimental units were maintained throughout the growing and finishing phases.

Grower phase

Approximately 2 wk before weaning, calves were vaccinated against IBR virus, BVD Type one, and two viruses, PI_3 virus, BRSV, and *Mannheimia haemolytica* (Bovi-Shield Gold One Shot; Zoetis, Parsippany, NJ) and against blackleg and disease caused by *Haemophilus somnus* (Ultrabac 7/Somubac; Zoetis). Calves from both systems were fence-line weaned. There were four groups of cow-calf pairs per treatment. Calves from all four replicates within a treatment were comingled in one pen. Cows from two replicates within treatment, chosen at random, were penned adjacent to the weaned calves to provide visual and auditory stimulation. Calves were fence-line weaned for 3 d and limit-fed GHat 2.0% of BW before being transported to the ruminant nutrition feedlot at ENREC. On arrival at the feedlot, calves received a panel tag and electronic identification tag in the left ear with an individual identification number and a metal tag in the right ear with the corresponding identification number. Calves, steers, and heifers were sorted into their previous cow replicate on day 5. Initial and ending BW measurements were collected (Silencer squeeze chute, Moly Mfg. Inc., Lorraine, KS) on two consecutive days and averaged following 5 d of limit feeding a diet consisting of (DM basis) 50.0% Sweet Bran (Cargill Corn Milling, Blair, NE) and 50.0% alfalfa hay at 2.0% of BW to minimize variation (Stock et al., 1983; Watson et al., 2013). Calves were implanted with 36 mg zeranol (Ralgro; Merck Animal Health, Madison, NJ) on day 0 and received an injection (Dectomax; Zoetis) to control gastrointestinal roundworms, lungworms, eyeworms, grubs, sucking lice, and mange mites. If calves were identified by feedlot personnel as exhibiting clinical signs of illness, they were removed from the pen, processed in a handling facility, diagnosed, and treated before returning to their home pen. Calves were maintained in their dam's original replicate for the grower and finisher phases. The previous dam replicates were determined by blocking cow age and stratifying cows by source (two original herd sources).

All calves received a common grower diet consisting of (DM basis) 35.0% grass hay (GH), 30.0% modified distillers grains plus soluble (MDGS), 30.0% dry-rolled corn (DRC), and 5.0% supplement (diet NEg = 1.05 Mcal kg^{-1} DM; Table 1). The grower diet was formulated to provide 200 mg^{-1}animal^{-1}d^{-1} monensin (Rumensin 90; Elanco Animal Health, Greenfield, IN). The nutrient composition of the grower diet is presented in Table 1. The TRAD grower phase was from 26 October 2018 to 16 February 2019 and 22 October 2019 to 18 February 2020 (year 1 and 2, respectively). The ALT grower phase occurred from 29 January 2019 to 22 May 2019, and from 5 February 2020, to 4 June 2020 (year 1 and 2, respectively). In February, TRAD and ALT calves were treated with 10 mL of 0.5% *Gamma-cyhalothrin* pour-on insecticide (Standguard; Elanco Animal Health) to control

Table 1. Ingredient composition of grower diet[1]

Ingredient, %	TRAD[2] Year 1[3]	ALT[2] Year 1[4]	TRAD[2] Year 2[5]	ALT[2] Year 2[6]
Dry-rolled corn	30.0	30.0	30.0	30.0
Grass hay	35.0	35.0	35.0	35.0
MDGS[7]	30.0	30.0	30.0	30.0
Fine ground corn	2.52	2.52	2.52	2.52
Limestone	1.98	1.98	1.98	1.98
Tallow	0.125	0.125	0.125	0.125
Salt	0.30	0.30	0.30	0.30
Beef trace mineral[8]	0.05	0.05	0.05	0.05
Vitamin ADE[9]	0.015	0.015	0.015	0.015
Monensin[10]	0.0116	0.0116	0.0116	0.0116
Nutrient composition, %				
Organic matter	92.94	90.09	90.19	90.68
Crude protein	16.01	16.16	15.05	13.05
Neutral detergent fiber	38.99	37.94	36.67	37.30
Acid detergent fiber	22.58	21.74	23.81	22.34
Ether extract	3.90	4.55	4.03	3.97

[1]All values represented on a dry matter basis.
[2]Treatments = traditional cow-calf system (TRAD) calving in April to June and utilizing perennial forage and corn residue grazing; alternative cow-calf system (ALT) calving in July to September and utilizing drylot, fall forage oat grazing, and corn residue grazing.
[3]Diet fed from October, 2018 to February, 2019.
[4]Diet fed from February to June, 2019.
[5]Diet fed from October, 2019 to February, 2020.
[6]Diet fed from February to June, 2020.
[7]Modified distillers grains plus solubles.
[8]Premix contained 10% Mg, 6% Zn, 4.5% Fe, 2% Mn, 0.5% Cu, 0.3% I, and 0.05% Co.
[9]Premix contained 1,500 IU of vitamin A, 3,000 IU of vitamin D, and 3.7 IU of vitamin E per gram.
[10]Rumensin 90, Elanco Animal Health, Indianapolis, IN. Formulated to provide 23.3 mg-1kg-1.

lice. Following day 113 and 120 (year 1 and 2, respectively) of the experiment, cattle followed the same limit-fed weighing protocol used for initial BW to determine ending BW for the grower phase. However, the ending BW was corrected for the BW gain during limit-feeding, predicted to be 0.45 kg d^{-1} (NASEM, 2016). Therefore, 2.7 kg was subtracted from the limit-fed weights, which represented BW gain for 6 d of limit-feeding.

Calves were housed in open feedlot pens (n = 16–20) with approximately 45.5 cm of linear bunk space and 35.3 m^2 of pen space per calf. Feed bunks were assessed once daily at approximately 0600 h for the presence of feed. Cattle were fed once daily between 0700 and 1000 h with ad libitum access to fresh water and feed. The bunks were managed to allow for 0.45 kg hd^{-1} (DM basis) increases in feed delivery when bunks were observed with less than 0.23 kg hd^{-1} (DM basis) remaining. When feed refusals were greater than 0.45 kg hd^{-1} for 3 consecutive d, then feed refusals were removed from the bunks, weighed, and sampled for DM determination. The management of calves in feedlot pens was the same for the grower and finisher phases. Diets were mixed and delivered using a truck-mounted feed mixer and delivery unit with scale measurements to the nearest 0.45 kg (Roto-Mix model 420, Roto-Mix, Dodge City, KS). All scales used for the experiment were calibrated twice annually.

Finisher phase

The ending BW for the grower phase was used to measure the initial BW for the finisher phase. The difference between the ending BW for the grower and the initial BW for the finisher is the BW gain assumed during the limit-fed period (0.45 kg d^{-1}). Steers were implanted on day 0 with 80 mg trenbolone acetate (TBA) and 16 mg estradiol (Revalor-IS; Merck Animal Health). Heifers were implanted on day 0 with 80 mg TBA and 8 mg estradiol (Revalor-IH; Merck Animal Health). Cattle were re-implanted on day 83 with 200 mg TBA and 20 mg estradiol (Revalor-200; Merck Animal Health). The TRAD finisher phase was from 22 February 2019 to 16 July 2019 (first shipping date; year 1), and 13 August 2019 (second shipping date; year 1), and from 25 February 2020 to 23 June 2020 (first shipping date; year 2), and 28 July 2020 (second shipping date; year 2). The ALT finisher phase was from 29 May 2019, to 29 October 2019 (first shipping date; year 1) and 10 December 2019 (second shipping date; year 1) and 10 June 2020 to 10 November 2020 (first shipping date; year 2), and 5 January 2021 (second shipping date; yearr 2). Cattle were adapted to a common diet over a 24-d and 25-d period (year 1 and t2, respectively), consisting of four adaptation diets. The amount of MDGS and supplements were held constant at 20.0 and 5.0% DM of the diet, respectively. The amount of DRC and HMC were increased, replacing a portion of GH at each adaptation diet. The first adaptation diet consisted of 17.5% DRC, 17.5% HMC, and 40.0% GH and was fed for 5 d to both treatments (year 1 and 2). The second adaptation diet consisted of 22.5% DRC, 22.5% HMC, and 30.0% GH and was fed for 5 d to both ALT and TRAD calves (year 1 and 2). The third adaptation diet consisted of 27.5% DRC, 27.5% HMC, and 20.0% GH and was fed for 7 d to TRAD calves (year 1), 8 d to ALT calves (year 1), and 8 d for both treatments (year 2). The fourth adaptation diet consisted of 31.5% DRC, 31.5% HMC, and 12.0% GH and was fed for 6 d to ALT calves (year 1), 7 d to TRAD calves (year 1), and 7 d to ALT and TRAD calves (year 2). In year 1, the finishing diet consisted of 33.5% DRC, 33.5% HMC, 20.0 % MDGS, 8.0% GH, and 5.0% supplement (DM; diet NEg = 1.32 Mcal kg^{-1} DM; Table 2). In year 2, due to feed seasonal limitations, the finishing diet consisted of 51.0% HMC, 30.0% Sweet Bran (Cargill Corn Milling), 15.0% corn silage, and 4.0% supplement (DM; diet NEg = 1.32 Mcal kg–^{1} DM; Table 2). In year 2 of the TRAD treatment, the first 13 d cattle were fed a diet of 51.0% HMC, 20.0% Sweet Bran (Cargill Corn Milling), 15.0% corn silage, 10.0% MDGS, and 4.0% supplement (diet not shown). The diet changes in year 2 resulted from a limited supply of MDGS from ethanol plants due to complications at the ethanol plant associated with the COVID-19 pandemic.

When comparing cattle of different types or treatments, cattle should be compared at equal fat points (Tedeschi et al., 2004). Therefore, marketing dates were selected to target 1.52 cm of backfat between the 12th and 13th rib. Due to backfat variation within a pen, calves within a pen were allotted to one of two marketing dates. These dates were based on backfat thickness determined by ultrasonography between the 12th and 13th rib. Ultrasound images were acquired using an Aloka SSD-500V (Hitachi Healthcare Americas) and were processed by The CUP Lab (Ames, IA). The initial fat thickness was subtracted from the targeted final fat thickness (1.52 cm) and divided by days to determine a fattening rate for each animal. A regression of

Table 2. Ingredient composition of finisher diets[1]

Ingredient, %	TRAD[2] Year 1[3]	ALT[2] Year 1[4]	TRAD[2] Year 2[5]	ALT[2] Year 2[6]
Dry-rolled corn	33.5	33.5	—	—
High-moisture corn	33.5	33.5	51.0	51.0
Sweet Bran[7]	—	—	30.0	30.0
Corn silage	—	—	15.0	15.0
MDGS[8]	20.0	20.0	—	—
Grass hay	8.0	8.0	—	—
Fine ground corn	2.29	2.29	1.88	1.88
Limestone	1.69	1.69	1.63	1.63
Tallow	0.125	0.125	0.100	0.100
Urea	0.50	0.50	—	—
Salt	0.30	0.30	0.30	0.30
Beef trace mineral[9]	0.05	0.05	0.05	0.05
Vitamin ADE[10]	0.015	0.015	0.015	0.015
Monensin[11]	0.0165	0.0165	0.0165	0.0165
Tylosin[12]	0.011	0.011	0.010	0.010
Nutrient composition, %				
Organic matter	96.11	92.98	93.23	94.68
Crude protein	13.93	14.70	13.79	12.63
Neutral detergent fiber	17.83	17.77	18.87	19.40
Acid detergent fiber	9.11	8.82	8.58	9.10
Ether extract	4.63	4.45	3.67	3.45

[1]All values represented on dry matter a basis.
[2]Treatments = traditional cow-calf system (TRAD) calving in April to June and utilizing perennial forage and corn residue grazing; alternative cow-calf system (ALT) calving in July to September and utilizing drylot, fall forage oat grazing, and corn residue grazing.
[3]Diet fed from February, 2019 to August, 2019.
[4]Diet fed from June, 2019 to December, 2019.
[5]Diet fed from February, 2020 to July, 2020.
[6]Diet fed from June, 2020 to January, 2021.
[7]Cargill Corn Milling, Blair, Nebraska.
[8]Modified distillers grains plus solubles.
[9]Premix contained 10% Mg, 6% Zn, 4.5% Fe, 2% Mn, 0.5% Cu, 0.3% I, and 0.05% Co.
[10]Premix contained 1,500 IU of vitamin A, 3,000 IU of vitamin D, and 3.7 IU of vitamin E per gram.
[11]Rumensin 90, Elanco Animal Health, Indianapolis, IN. Formulated to provide 33.0 mg-1kg-1.
[12]Tylan 40, Elanco Animal Health, Indianapolis, IN. Formulated to provide 9.7 mg-1kg-1.

increasing backfat over DOF was determined, and the number of days until the target endpoint backfat thickness was calculated (data not shown). The TRAD cattle were on feed for 145 and 173 d (first and second shipping dates, respectively; year 1). The ALT cattle were on feed for 154 and 196 d (first and second shipping dates, respectively; year1). In year 2, TRAD cattle were on feed for 120 and 155 d (first and second shipping dates, respectively). In year 2, ALT cattle were on feed for 154 and 210 d (first and second shipping dates, respectively). Cattle were loaded on trucks between 1600 and 1800 h and transported to a commercial abattoir (Greater Omaha Packing Co, Inc.; Omaha, NE), located 66.1 km from ENREC, for harvest the next morning. On the day of shipping, cattle were offered 50% of the previous day's intake. On the first shipping date, approximately half of each sex was identified, sorted, and loaded for shipment, leaving the remaining steers and heifers in pen for continued feeding. Prior to shipping, cattle were brought to the handling facility, pen weighed (Mobile Group Livestock Scale MAS-M, Rice Lake, WI), and shrunk (pen-scale weight ÷ number of animals on pen scale ÷ 0.96) to determine live final BW. Hot carcass weight (HCW) was collected on the day of harvest. Following a 48-h chill, *longissimus* muscle (LM) area, 12th-rib fat thickness, and USDA marbling score were collected.

Performance and health calculations

Mortality percentage was calculated as the total number of animals that died from a group divided by the total number of animals in that respective group. The percentage of animals removed from the experiment, excluding deads, was determined by dividing the number of animals removed due to injury or chronic illness per group by the total number of animals from that respective group. Morbidity percentage was calculated as the number of animals in a group treated at least once, divided by the total number of animals in that respective group.

Carcass-adjusted final BW was calculated using HCW divided by a common dressing percent of 63%. The average daily gain was calculated as the difference in initial BW and carcass-adjusted final BW divided by the total days on feed (DOF) in the finisher phase. Adjusted final BW (AFBW) was calculated as $((1.316 \times \text{HCW}) + 32) + [(28 - \text{EBF}) \times 14.26]) \div 0.891$ from Guiroy et al. (2001). Dry matter intake (DMI) was calculated by dividing the total feed delivered to each pen, minus feed refusals, divided by the total number of animal head days for each pen. Carcass-adjusted ADG was calculated by subtracting initial BW from carcass-adjusted final BW, then dividing by the number of DOF. Carcass-adjusted gain to feed (G:F) was calculated by dividing carcass-adjusted ADG by DMI. Yield grade was calculated (CYG) as $2.5 + (6.35 \times$ 12th-rib fat thickness, cm$) - (2.06 \times$ LM area, cm$^2) + (0.2 \times 2.5$ KPH fat, %$) + (0.0017 \times$ HCW, kg), where KPH fat was assumed to be 2.5 % (USDA, 1997). Empty body fat (EBF) was calculated as $17.76207 + (4.68142 \times$ 12th-rib fat [cm]$) + (0.01945 \times$ HCW [kg]$) + (0.81855 \times \text{QG}) - (0.06754 \times$ LM area [cm^2]).

Feed sample collection and analysis

Feed ingredient samples were collected weekly, weighed, and then dried in a 60 °C forced-air oven to determine DM concentration (AOAC, 1999; method 934.01). Dried feed samples were ground through a 1-mm screen with a Wiley mill (Model 4 Thomas Scientific, Swedesboro, NJ) and composited by month. Ash and OM were measured by placing crucibles containing each feed ingredient sample in a muffle furnace for 6 h at 600 °C (AOAC, 1999; method 945.05). Neutral and acid detergent fiber analyses were conducted using the procedures described by Van Soest et al. (1991) with modifications to the analysis of corn and byproducts described by Buckner et al. (2013). Additionally, two doses (0.5 mL/dose) of alpha-amylase (Catalog # FAA, Ankom Technologies, Macedon, NY) were added during the hour-long reflux in NDF solution. The modification applied to the byproducts was a biphasic lipid extraction (Bremer et al., 2010) prior to NDF analysis (Buckner et al., 2013). When refusals were present, orts were weighed, sampled, and stored frozen until analysis of DM. The DM of orts was determined by placing samples in a 60 °C forced-air oven for 48 h (AOAC, 1999; method 934.01). Crude protein (CP) was also analyzed using a combustion-type N analyzer (FlashSmart N/Protein Analyzer CE Elantech, Inc., Lakewood, NJ).

GHG measurements

Large, pen-scale chambers were used to measure CH_4 and CO_2 production by monitoring the concentrations of CO_2 and CH_4 of air entering and exiting the chamber multiplied by flow rate. A detailed description of this method is found in Winders et al. (2020). Gas concentrations were analyzed using an LI-7700 CH_4 analyzer and LI-7500DS CO_2/H_2O Analyzer (LI-COR Biosciences, Lincoln, NE). Schematic of chamber layout is presented in Winders et al. (2020). The methane analyzer operates using near-infrared laser and wavelength modulation spectrometry to detect the absorption of CH_4 in the air sample. The resolution of this instrument is 5 ppb at 10 Hz in typical ambient concentrations (2 ppm CH_4). The carbon dioxide analyzer uses nondispersive infrared spectroscopy to measure CO_2 and water densities in the air sample. The air sampling system cycled between three sampling lines; one line in each chamber (east and west) and one line outside, located on the south side for ambient air supply, which corresponds to the ambient air inlet to the pen chambers. Each cycle was 20 min, during which each side of the barn and ambient air was sampled. Data were captured at 1 Hz. Concentrations of CH_4 and CO_2 were different between the four sampling points for each 20-min cycle. The start of the first 20-min interval was determined for each day's data based on the change in air concentration. Data before the start of the first interval were removed (between 0 and 19 min per day). Then, the mean concentration of CH_4 and CO_2 was calculated for every 20-min cycle using R software (R Foundation, Indianapolis, IN). The daily mean concentration of CH_4 and CO_2 was subsequently calculated.

Data were further processed so that the 24-h period from feeding to feeding was considered a day. Feeding times were recorded by feeding software in the feed delivery truck. Air was pulled through each pen and exited through the fans, with a sampling line positioned above the fans. Fans were validated twice for airflow rate before and after the experiment (FANS System, Iowa State University). Airflow through the chambers with two fans running was 1,274 $L^{-1}s^{-1}$. Air was sampled in each pen using a sampling line with a pump and controlled with a solenoid system and data logger. Solenoids switch sampling between the ambient line, pen one, and pen two, allowing each pen to be sampled for six min. After cycling through the sampling of the two pens and ambient air, an additional ambient air sample was collected for 2 min to complete a 20-min cycle. A 2-min ambient sampling allows for easy recognition of when the cycle resets. When data were being analyzed, for example, pen one always follows the 2-min sampling period. An adequate time of 6 min allows the system to be flushed between pen one and pen two sampling periods and provides ambient concentrations of CO_2 and CH_4. Emissions data were averaged across each 6-min time point, excluding the first 60 s to avoid including lower measurements as gas acclimates to solenoid switching. Gas emissions per day was an average of all 6-min measurements per pen and extrapolated to a 24-h period.

Calves from one pen were split evenly between both chambers of the barn after sorting to equalize heifers and steers in each chamber. After 5 d, calves were removed and the manure accumulated over the previous 5 d was monitored for GHG emissions for 24 h. On the seventh day, manure was removed from the barn using a skid loader, and then a final 24-h measurement of the empty barn with no manure or cattle was performed for baseline measurements. The GHG emissions from manure were calculated by the difference from baseline. It was assumed that the GHG contributions from manure were equal to one-half of what was measured during the 24-h period since, on average, half of the accumulated manure was present in the barn at any one time during the 5-d measurement period. The GHG contribution from manure was subtracted from the total GHG emissions to determine GHG emissions from the cattle. This correction was small, averaging 1.32 g of CH_4 and 130 g of CO_2 animal^{-1} day^{-1}. When the 7-d cycle was complete, the cycle was repeated for the other three replicates in the production system. Calves from both systems had GHG emissions collected during for the same DOF.

Across the 2-yr of data collection, a total of 80 measurement days were acceptable (each day contained approximately 70 measurements, one for every 20 min for each chamber). About 3 d were not used due to incomplete data, power outages, or malfunctions with the sensor system. There were 5 d for each gas collection period. The means of the 5 d of CO_2 and CH_4 emissions from each chamber were used to calculate GHG emissions from each replicate within groups. These were used to calculate CO_2 and CH_4 emissions expressed per kilogram of DMI. The CO_2 and CH_4 values per kilogram of DMI were used to calculate grams of CO_2 and CH_4 per kilogram of gain, per animal daily, and the total over the entire feeding period based on average intake from each replicate. Cattle in TRAD and ALT were slaughtered to target equal backfat thicknesses (1.52 cm), which resulted in treatment differences in the number of DOF and feed intakes.

Statistical analysis

Cattle growth performance and carcass characteristics were analyzed using the GLIMMIX procedures of SAS 9.4 (SAS Institute Inc., Cary, NC), where a group of calves from a previous cow-calf system served as the experimental unit (n = eight groups/treatment). The model included treatment, which was the previous cow-calf system, and block as fixed effects. Block was previous cow-calf replicate within treatment that were initially blocked by cow age and stratified by original herd source. Year was included as a random effect. The proportion of heifers and twins was tested as covariates but was not significant ($P > 0.11$) except for carcass-adjusted G:F in the finisher phase. Therefore, the covariate of sex, as a proportion of heifers per replicate, was included in the model for the dependent variable, carcass-adjusted G:F, but removed from all other dependent variable models. Morbidity data were analyzed using the GLIMMIX procedure of SAS 9.4 (SAS Institute Inc.) with a binomial model with replicate as the experimental unit and fixed effects of treatment and block. Year was included as a random effect. The model for morbidity data specified a solutions function for the binomial response, with the total number of cattle per replication serving as the denominator.

Methane and CO_2 emissions were analyzed using the MIXED procedure of SAS 9.4 (SAS Institute, Inc. Cary, NC) with the pen as the experimental unit and year as a random variable. Total emissions (grams animal^{-1} day^{-1}) was analyzed with days in barn as repeated measures using the minimum values of Akaike's information criterion to select compound symmetry as the covariant structure. Means were considered statistically significant when $P \leq 0.05$ and a tendency when $0.05 < P \leq 0.10$.

Results and Discussion

Climate

All climate data are for Lincoln, NE (Table 3; NWS, 2021). In TRAD year 1 grower phase (October 2018 to February 2019), temperatures ranged from a low of −22.8 °C in January to a high of 34.4 °C in October. Total precipitation for that period was 23.92 cm, with a monthly high of 8.23 cm in December. In ALT year 1 grower (February 2019 to June 2019), temperatures ranged from a low of −22.8 °C in January to a high of 37.2 °C in June. Total precipitation for that period was 45.09 cm, with a monthly high of 18.52 cm in May (NWS, 2021). In TRAD year 2 grower phase (October 2019 to February 2020), temperatures ranged from a low of −19.4 °C in January to a high of 26.1 °C in October. Total precipitation for that period was 24.06 cm, with a monthly high of 11.91 cm in October. In ALT year 2 grower phase (February 2020 to June 2020), temperatures ranged form a low of −19.4 °C in January to a high of 35.6 °C in June. Total precipitation for that period was 26.85 cm, with a monthly high of 11.43 in May.

In TRAD year 1 finisher phase (February 2019 to August 2019), temperatures ranged from a low of −22.8 °C in March to a high of 37.2 °C in June and July. Total precipitation for that period was 61.56 cm, with a monthly high of 18.52 cm in May. In ALT year 1 finisher phase (June 2019 to December 2019), temperatures ranged from a low of −16.7 °C in November to a high of 37.2 °C in June and July. Total precipitation for that period was 58.44 cm, with a monthly high of 11.91 cm in October. In TRAD year 2 finisher phase (February 2020 to July 2020), temperatures ranged form a low of −18.9 °C in February to a high of 35.6 °C in June and July. Total precipitation for that period was 36.75 cm, with a monthly high of 13.18 cm in July. In ALT year 2 finisher phase (June 2020 to January 2021), temperatures ranged from a low of −15.6 °C in December to a high of 36.1 °C in September. Total precipitation for that period was 31.53 cm, with a monthly high of 13.18 cm in July.

Grower phase

As designed, calf age at weaning was not different ($P = 0.76$) at 168 d for both treatments (Table 4). Due to differences in weaning BW in the cow-calf phase (Carlson et al., 2022), the initial BW for the grower phase was 44 kg lower ($P < 0.01$; Table 4) for ALT calves compared to TRAD calves. Ending BW was 24 kg lower ($P < 0.01$) for ALT calves compared to TRAD following the growing phase. However, ALT calves gained 0.17 kg d^{-1} more ($P < 0.01$) than TRAD. There was no difference ($P = 0.17$) for DMI between treatments. Thus, ALT calves were 14.6% ($P < 0.01$) more efficient than TRAD. It is not surprising that ALT calves experienced compensatory gain. The ALT calves compensated, and ADG was 12.1% greater, possibly due to nutrient restriction or weather effects impacting maintenance and growth during the cow-calf phase. These observations of compensatory growth are consistent with other systems in which calves that were restricted before weaning compensated during the growing phase (Cole et al. 2015).

According to White et al. (1987), compensatory gain occurs early in the recovery period, and the extent depends on the previous level of dietary restriction. Greenwood and Café (2007) observed compensatory gain during the backgrounding period in calves under nutrient restriction pre-weaning. The calves were 66 kg lighter at weaning and had similar ADG but lower DMI in the backgrounding phase. In addition, heifer calves that were nutrient restricted were 65 kg lighter at weaning but only 25 kg lighter at 30 mo of age. A theory

Table 3. Monthly temperature (°C) and precipitation (cm) for year 1 (2018–2019) and year 2 (2019–2020) for two different cow-calf systems[1]

Item	Temperature (°C)						Precipitation (cm)				System[2]	
	Low	High	Low	High	Low	High						
	2018	2018	2019	2019	2020	2020	2018	2019	2020	30-yr[3]	TRAD	ALT[4]
January	−28.3	13.3	−22.8	16.1	−19.4	10.6	1.04	1.75	3.28	1.85	Grower	Finisher
February	−21.1	18.3	−21.7	14.4	−18.9	17.8	1.88	4.04	0.33	2.26	G/F[5]	Grower
March	−11.1	22.8	−22.8	24.4	−7.8	23.9	6.73	6.73	4.24	3.94	Finisher	Grower
April	−12.2	27.8	−4.4	30.6	−8.9	30.6	1.7	2.92	2.24	6.83	Finisher	Grower
May	6.1	37.8	1.7	34.4	0.6	32.8	5.66	18.52	11.43	12.47	Finisher	Grower
June	11.1	38.3	7.8	37.2	11.7	35.6	22.43	11.13	5.33	11.38	Finisher	G/F[6]
July	13.9	36.1	7.8	37.2	16.1	35.6	3.43	11.13	13.18	8.26	Finisher[7]	Finisher
August	10	35.6	10.6	35	9.4	35	11.05	7.09	3.23	8.43	Finisher[8]	Finisher
September	5	35.6	8.9	34.4	5.6	36.1	18.11	8.64	4.11	7.37	–	Finisher
October	−2.8	34.4	−7.8	26.1	−8.9	31.1	6.88	11.91	1.02	5.44	–	Finisher
November	−14.4	17.2	−16.7	23.3	−10	28.3	3.02	2.01	3.05	3.3	Grower	Finisher
December	−15.6	13.3	−12.8	15.6	−15.6	18.9	8.23	6.53	3.05	3	Grower	Finisher

[1]All data were acquired from https://www.weather.gov/oax/monthly_climate_records.
[2] Treatments = traditional cow-calf system (TRAD) calving in April to June and utilizing perennial forage and corn residue grazing; alternative cow-calf system (ALT) calving in July to September and utilizing drylot, fall forage oat grazing, and corn residue grazing.
[3]30-yr historical precipitation from 1991 to 2020 from NOAA (2020).
[4]ALT year 2 finisher phase were on feed until the first week of January 2021: monthly low −13.3°C, monthly high – 12.8°C, monthly precipitation 3.89 cm.
[5]G/F = TRAD year 1 end of grower phase and start of finisher phase.
[6]G/F = ALT year 1 end of grower phase and start of finisher phase.
[7]TRAD year 2 finisher phase ended in July 2020.
[8]TRAD year 1 finisher phase ended in August 2019.

Table 4. Comparison of a traditional spring-calving pasture-based cow-calf system (TRAD) to an alternative fall-calving cow-calf system utilizing drylot and oats grazing (ALT) on post-weaning calf growth performance on a grower diet

	Treatments[1]		SEM[2]	*P*-Value
	TRAD	ALT		
Groups, *n*	8	8	–	–
Days on feed[3]	117	117	–	–
Initial BW,[4] kg	229	185	4.9	<0.01
Ending BW, kg	371	347	2.9	<0.01
DMI,[5] kg	8.89	8.66	0.109	0.17
ADG,[6] kg	1.22	1.39	0.020	<0.01
G:F[7]	0.137	0.157	0.003	<0.01
Mortality, %	0.00	8.66	–	–
Removed,[8] %	0.00	0.00	–	–
Morbidity,[9] %	37.68	5.26	11.020	<0.01

[1]Treatments = traditional cow-calf system (TRAD) calving in April to June and utilizing perennial forage and corn residue grazing; alternative cow-calf system (ALT) calving in July to September and utilizing drylot, fall forage oat grazing, and corn residue grazing.
[2]SEM = Standard error of the mean.
[3]Days on feed for year 1 and year 2 (113 d and 120 d, respectively).
[4]BW = Body weight.
[5]DMI = Dry matter intake.
[6]ADG = Average daily gain.
[7]G:F = gain to feed ratio.
[8]Percentage of calves removed due to health or injury.
[9]Percentage of calves treated for morbidity at least once.

Table 5. Comparison of a traditional spring-calving pasture-based cow-calf system (TRAD) to an alternative fall-calving cow-calf system utilizing drylot and oats grazing (ALT) on post-weaning calf greenhouse gas emissions during the grower phase

	Treatment[1]		SEM[2]	*P*-value
	TRAD	ALT		
CH_4				
Per animal per day, g	121.8	122.9	3.42	0.79
Per kilogram DMI,[3] g	16.12	15.74	0.53	0.62
Per kilogram ADG,[4] g	118.39	98.77	5.58	<0.01
Total per animal, kg	16.69	15.88	0.76	0.31
CO_2				
Per animal per day, g	4,948	4,713	193	0.25
Per kilogram DMI, g	656.54	599.44	40.57	0.18
Per kilogram ADG, g	4,823.71	3,752.26	279.35	< 0.01

[1]Treatments = traditional cow-calf system (TRAD) calving in April to June and utilizing perennial forage and corn residue grazing; alternative cow-calf system (ALT) calving in July to September and utilizing drylot, fall forage oat grazing, and corn residue grazing
[2]SEM = Standard error of the mean.
[3]DMI = Dry matter intake.
[4]ADG = Average daily gain.

of why compensatory growth occurs is that lower maintenance requirements due to lower visceral mass (Yambayamba et al., 1996) as a result of feed restriction and greater protein synthesis followed by increased fat deposition (Hornick et al. 2000). Compensatory gain in calves measured pre- and post-weaning have been observed (Gillespie, 2013) comparing calves that were lighter at weaning or lighter due to the lower plane of nutrition prior to compensatory growth. The greater gain in ALT calves during the grower phase compared to TRAD calves is consistent with others in the literature and resulted in subsequent effects on methane emissions relative to performance measures.

During the grower phase, CH_4 emissions expressed as animal^{-1} d^{-1} and kg^{-1} DMI were not different ($P \geq 0.62$) between treatments (Table 5). Due to differences in ADG, the g CH_4 kg^{-1} ADG was 16.5% lower in ALT calves. Total CH_4 over the grower phase (16.7 and 15.9 kg for TRAD and ALT, respectively) was not different ($P = 0.31$). Carbon dioxide was not different for animal d^{-1} or kg^{-1} DMI but was 22% lower ($P < 0.01$) in g CO_2 kg^{-1} ADG for ALT calves due to lesser BW in the grower phase than TRAD calves. There was a tendency ($P = 0.07$) for total CO_2 animal^{-1} to be greater for TRAD than ALT calves. There were no differences ($P = 0.15$) in GE intake between treatments. These data indicate that the cow-calf system did not affect GHG emissions intensity, but absolute methane emissions were greater for TRAD calves per unit of growth due to greater daily gain and gain efficiency for ALT calves.

Finisher phase

Initial BW for the finisher phase was less (P <0.01) for ALT calves than TRAD calves resulting from lower ending BW for ALT calves in the grower phase (Table 6). Live final BW was greater ($P = 0.01$) by 28 kg for the ALT calves compared to TRAD. However, carcass-adjusted final BW did not differ ($P = 0.21$) between treatments. DMI did not differ ($P = 0.33$) between treatments. However, carcass-adjusted ADG was lesser ($P = 0.02$), by 0.29 kg d^{-1}, for ALT calves compared to TRAD, a response largely driven by improved ADG of TRAD calves in the second year of the study. In year 2, TRAD calves gained 0.76 kg d^{-1} more than the TRAD calves in year 1 of the finisher phase. For comparison, the observed carcass-adjusted ADG in year 2 for ALT calves for was 0.08 kg d^{-1} greater compared to year 1. Lower ADG and no difference in DMI lead to poorer ($P = 0.01$) carcass-adjusted G:F for ALT calves compared to TRAD calves. The improvements in carcass-adjusted ADG observed in year 2 for the TRAD treatment are difficult to explain but may be related to temperatures, especially early in the finishing period. Cattle in the TRAD treatment were fed a finishing diet from February to August, 2019 (year 1) and from February to July, 2020 (year 2) and low temperatures were moderate in March of year 2 (Table 3). The differences in weather could have altered the maintenance requirements between TRAD and ALT treatments.

HCW did not differ (P =0.20) between treatments. These results differ from previous reports (Greenwood and Cafe, 2007) where restricted, lighter weight calves at weaning yielded 25 kg less carcass weight at an equivalent age to non-restricted calves. However, in the current experiment, pre-weaning restriction did not impact HCW. However, ALT calves required an additional 27 DOF. LM area was greater ($P = 0.04$) for ALT than TRAD calves. DOF were 168 and 141 for ALT and TRAD calves, respectively, to harvest cattle at a predicted 12th-rib backfat thickness of 1.52 cm. While these differences in DOF attempted to equilibrate backfat thickness between the two treatments, backfat thickness still differed ($P = 0.05$) between treatments. DOF calculated from ultrasound measures of backfat were underestimated for TRAD calves in year 2 due to the large numerical improvement in growth performance for TRAD calves in year 2. Because of treatment differences for backfat and LM area, calculating adjusted

Table 6. Comparison of a traditional spring-calving pasture-based cow-calf system (TRAD) to an alternative fall-calving cow-calf system utilizing drylot and oats grazing (ALT) on post-weaning calf growth performance on a finishing diet

	Treatment[1]		SEM[2]	*P*-value
	TRAD	ALT		
Groups, *n*	8	8	–	–
DOF[3]	141	168	–	–
Initial BW, kg	374	350	2.9	< 0.01
Live final BW,[4] kg	596	624	5.1	< 0.01
Carcass-adj. final BW,[5] kg	605	615	6.2	0.15
AFBW,[6] kg	488	511	6.4	0.03
DMI,[7] kg	10.5	10.8	0.28	0.33
Carcass-adj. ADG,[8] kg	1.81	1.52	0.218	0.02
Carcass-adj. G:F[9]	0.173	0.139	0.0151	0.01
Carcass characteristics				
HCW,[10] kg	381	388	3.8	0.14
LMA,[11] cm2	89.5	93.2	1.74	0.04
Backfat, cm	1.65	1.51	0.043	0.05
Marbling score[12]	539	532	14.3	0.73
Calculated YG[13]	3.4	3.1	0.07	0.03
EBF,[14] %	30.8	30.0	0.30	0.07
Mortality, %	0.72	1.55	–	–
Removed,[15] %	0.91	0.96	–	–
Morbidity, %	40.36	20.88	12.210	0.23

[1]Treatments = traditional cow-calf system (TRAD) calving in April to June and utilizing perennial forage and corn residue grazing; alternative cowcalf system (ALT) calving in July to September and utilizing drylot, fall forage oat grazing, and corn residue grazing.
[2]SEM = Standard error of the mean.
[3]DOF = Days on feed. Treatments were fed to predict 1.52 cm of 12th-rib fat thickness.
[4]BW = Body weight.
[5]HCW divided by dressing percent (0.63).
[6]Adjusted final BW calculated as [(1.316 × HCW) +32] + [(28 – EBF) × 14.26] ÷ 0.891 from Guiroy et al. (2001).
[7]DMI = Dry matter intake.
[8]ADG = Average daily gain.
[9]G:F = Gain to feed ratio. Covariate of proportion of heifers was included in the model and found to be significant (P = 0.03) (this replaces current #5).
[10]HCW = Hot carcass weight.
[11]LMA = Longissimus muscle area.
[12]Marbling score: 400 = small00, 500 = modest00.
[13]YG = Yield grade. Calculated as 2.5 + (6.35 × 12th-rib fat thickness, cm) – (2.06 × LM area, cm2) + (0.2 × 2.5 KPH fat, %) + (0.0017 × HCW, kg) where KPH fat was assumed to be 2.5 % (USDA, 1997).
[14]EBF = Empty body fat. Calculated as 17.76207 + (4.68142 × 12th-rib fat) + (0.01945 × HCW) + (0.81855 × QG) – (0.06754 × LM area) from Guiroy et al. (2001).
[15]Percent of calves removed due to health or injury.

Table 7. Comparison of a traditional spring-calving pasture-based cow-calf system (TRAD) to an alternative fall-calving cow-calf system utilizing drylot and oats grazing (ALT) on post-weaning calf greenhouse gas emissions during the finisher phase

	Treatment[1]		SEM[2]	*P*-value
	TRAD	ALT		
CH_4				
g/animal/d	125.0	145.2	11.4	0.10
g/kg DMI[3]	11.8	13.4	1.0	0.14
g/kg ADG[4]	69.9	95.2	9.8	0.02
Total kg/animal	18.4	27.0	3.1	0.01
CO_2				
g/animal/d	7,551	7,111	352	0.23
g/kg DMI	717	662	35	0.14
g/kg ADG	1,225	1,424	174	0.06

[1]Treatments = traditional cow-calf system (TRAD) calving in April to June and utilizing perennial forage and corn residue grazing; alternative cow-calf system (ALT) calving in July to September and utilizing drylot, fall forage oat grazing, and corn residue grazing.
[2]SEM = Standard error of the mean.
[3]DMI = Dry matter intake.
[4]ADG = Average daily gain.

final BW (AFBW; Guiroy et al. 2001), allows treatments to be compared on equal EBFcomposition. Adjusted final BW, calculated using 12th-rib backfat, LM area, HCW, and marbling score, was greater ($P = 0.03$) for ALT than TRAD calves. Greater AFBW for ALT calves may be due to improved growth performance for TRAD calves leading to a greater degree of fat deposition prior to slaughter. Marbling score did not differ ($P = 0.73$) between treatments. Consequently, EBF was calculated according to Guiroy et al. (2001) to account for differences in carcass composition. Carcass-adjusted EBF tended ($P = 0.07$) to be lower for ALT than TRAD calves. As previously discussed, TRAD calves appear to have had a greater rate of backfat deposition throughout the finisher phase with no differences in marbling. Based on these findings, lower BW at weaning in ALT calves may have affected their physiological maturity since it required more DOF and greater BW and yielded less backfat compared to TRAD calves.

There was a tendency ($P = 0.10$) for greater methane emissions for ALT calves as animal day^{-1} compared to TRAD calves (125 vs. 145 g animal d^{-1}, respectively; Table 7). Gross energy (GE) intake was not different between treatments ($P = 0.26$). Total methane per animal over the finisher phase was 47% greater ($P = 0.01$) for ALT than TRAD calves. This was primarily due to greater DOF for ALT than TRAD calves (168 vs. 141 d, respectively). The resulting DOF is an important distinction that affects models predicting GHG. White and Capper (2013) modeled the economic and environmental impacts of improving ADG or final BW by 15%. These improvements would decrease, per unit of beef produced, total CH_4 by 12.8% and 15.9%, respectively, for ADG and final BW. Each day an animal is on feed results in greater emissions of GHG. Maintaining ADG but improving final BW would increase the amount of product when calculating carbon per unit of product. In the case of this system, lower BW at the start of the grower phase results in lower BW at the end of the period despite greater ADG. As previously described, Greenwood and Café (2007) observed that nutrient-restricted calves pre-weaning maintained lower BW to slaughter and had 25 kg lower HCW. However, the restriction during pre-weaning had no effect on growth during the finisher phase, unlike the current experiment. Additionally, feed restriction has been shown to up-regulate some methanogens' activity while decreasing others' activity (McGovern et al., 2017).

Combined grower and finisher phases

When analyzing data from the entire feeding period, TRAD calves were 44 and 24 kg heavier at the start of the grower and finisher phases, respectively (Table 8). At slaughter, TRAD calves were 10 kg lighter, but had greater backfat

Table 8. Comparison of a traditional spring-calving pasture-based cow-calf system (TRAD) to an alternative fall-calving cow-calf system utilizing drylot and oats grazing (ALT) on post-weaning calf growth performance during grower and finisher phases

	Treatment[1]		SEM[2]	*P*-value
	TRAD	ALT		
Groups, *n*	8	8	–	–
Initial growing BW, kg	229	185	4.9	<0.01
Initial finishing BW, kg	374	350	5.1	<0.01
Carcass-adjusted final BW,[3] kg	605	615	6.2	0.15
HCW,[4] kg	381	388	3.8	0.14
DMI,[5] kg	9.8	9.9	0.1	0.45
ADG,[6] kg	1.54	1.47	0.05	0.15
G:F[7]	0.157	0.148	0.21	0.15
Backfat, cm	1.65	1.51	0.043	0.05
GE[8] intake, Mcal/d	92.3	90.8	1.38	0.27
CH_4				
g/animal/d	132.7	141.9	6.37	0.17
g/kg DMI	6.12	6.44	0.28	0.26
Total/animal, kg	35.1	42.9	2.9	0.02
g/kg HCW	92.2	110.7	8.3	0.04
CO_2				
g/animal/d	6,805	6,359	255	0.10
g/kg DMI	693.5	640.2	29.43	0.09
Total/animal, kg	1,803.0	1,899.0	74.0	0.22
g/kg HCW	4,736.8	4,913.9	224.9	0.44

[1]Treatments = traditional cow-calf system (TRAD) calving in April to June and utilizing perennial forage and corn residue grazing; alternative cow-calf system (ALT) calving in July to September and utilizing drylot, fall forage oat grazing, and corn residue grazing.
[2]SEM = Standard error of the mean.
[3]BW = Body weight.
[4]HCW = Hot carcass weight.
[5]DMI = Dry matter intake.
[6]ADG = Average daily gain.
[7]G:F = Gain to feed ratio.
[8]GE = Gross energy.

depth than ALT calves (1.65 vs. 1.51 cm respectively, P = 0.05) even though ALT calves were fed for 27 d longer. Across the entire feeding period, there were no differences in DMI, G:F, or ADG between treatments. GE intake (Mcal d^{-1}) and loss from CH_4 (Mcal d^{-1} and % of GE) were not different ($P \geq 0.23$) between treatments. Methane emissions were not different ($P \geq 0.17$) between treatments for g kg^{-1} DMI and g $animal^{-1}$ d^{-1}. Greater DOF increased total methane by 22% (P = 0.02) and methane kg^{-1} of HCW by 20% (P = 0.04), respectively, in ALT calves. There was a tendency for CO_2 emissions day^{-1} and kg^{-1} DMI to be greater for TRAD calves (P = 0.10). But, more CO_2 was emitted over the feeding period for ALT than TRAD calves, resulting in no differences ($P \geq 0.22$) in total CO_2 $animal^{-1}$ or CO_2 kg^{-1} HCW between treatments. On average, more GHG emissions originate from the finishing period due to more DOF. In a life-cycle assessment of beef systems by Stackhouse-Lawson et al. (2012), when calculating total CO_2e, the cow-calf, stocker, and feedlot sectors were responsible for 79%, 16%, and 5% of the methane, but 69%, 14%, and 17%, respectively of the CO_2e from a theoretical California beef system. Similarly, Basarab et al. (2012) estimated post-weaning emissions of calf-fed and yearling-fed beef production systems and reported cattle directly placed into the feedlot post-weaning decreased their carbon footprint by 2.7% per kilogram HCW compared to backgrounding for 299 d. In the current study, all calves were treated equally. However, given the greater gains and gain efficiency in the finisher phase, fewer days being fed a high-forage diet would likely result in less total GHG emissions from methane.

The hypothesis that post-weaning calf growth performance, carcass characteristics, and methane and carbon dioxide emissions would not differ for calves raised in a partial-intensive or extensive cow-calf production system was not supported by the results of this experiment. Calves from the partially intensive cow-calf system had lower BW throughout the growing and finishing period and required 27 additional DOF to reach market and produced more total methane. Production systems that reduce DOF to achieve a similar HCW will result in less methane production.

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Conflict of Interest Statement

Authors have nothing to declare and no conflicts of interest.

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