The effects of feeding increasing concentrations of corn oil on energy metabolism and nutrient balance in finishing beef steers

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ABSTRACT: The use of an added lipid is common in high-concentrate finishing diets. The objective of our experiment was to determine if feeding increasing concentrations of added dietary corn oil would decrease enteric methane production, increase the ME:DE ratio, and improve recovered energy (RE) in finishing beef steers. Four treatments were used in a replicated 4 × 4 Latin square (n = 8; initial BW = 397 kg ± 3.8). Data were analyzed using a Mixed model with the fixed effects of period and dietary treatment and random effects of square and steer within square. Treatments consisted of: (1) 0% added corn oil (Fat-0); (2) 2% added corn oil (Fat-2); (3) 4% added corn oil (Fat-4); (4) 6% added corn oil (Fat-6). Dry matter intake or GE intake did not differ across diets (P ≥ 0.39). As a proportion of GE intake, fecal energy loss, DE, and urinary energy loss did not differ by treatment (P ≥ 0.27). Additionally, methane energy produced decreased linearly as corn oil increased in the diet (P < 0.01). No differences were detected in ME loss as a proportion of GE intake (P ≥ 0.98). However, the ME:DE ratio increased linearly (P < 0.01; 93.06, 94.10, 94.64, and 95.20 for Fat-0, Fat-2, Fat-4, and Fat-6, respectively) as corn oil inclusion increased in the diet. No differences in RE or heat production as a proportion of GE intake were noted (P ≥ 0.59) and dry matter digestibility did not differ across diets (P ≥ 0.36). Digestibility of NDF as a proportion of intake responded quadratically increasing from 0% corn to 4% corn oil and decreasing thereafter (P = 0.02). Furthermore, ether extract digestibility as a proportion of intake responded quadratically, increasing from 0% to 4% corn oil inclusion before reaching a plateau (P < 0.01). As a proportion of GE intake, RE as protein decreased linearly as corn oil was increased in the diet (P < 0.01). As a proportion of total energy retained, RE as protein decreased when corn oil increased from 0% to 6% of diet DM (P < 0.01). Similarly, RE as fat and carbohydrate as a proportion of GE intake increased linearly as corn oil increased in the diet (P = 0.05). From these data, we interpret that adding dietary fat decreases enteric methane production and increases the ME:DE ratio, in addition to increasing the amount of energy retained as fat and carbohydrate.

Key words: dietary fat, energetics, finishing cattle

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INTRODUCTION

Fat is commonly added to high-concentrate finishing diets to boost the NEnergy concentration and improve overall gain. Vasconcelos and Galyean (2007) reported that 71% of consulting feedlot nutritionists recommended added fat to their clients, primarily in the form of tallow and yellow grease. The average concentration of recommended fat reported by the 2007 survey was 3.0% of DM, while the mode was 3.1% of DM (Vasconcelos and Galyean, 2007). In a more recent consulting feedlot nutritionist survey,
54.2% of the clients added fat to finishing diets, which could be associated with increased costs of fat or the use of more distillers grains that contain fat (Samuelson et al., 2016).

According to the NRC (2000), the ratio of ME to DE is 80%, but can vary considerably as a result of intake, age of animal, and feed source. Vermorel and Bickel reported that the ME:DE ratio ranged from 0.82 to 0.93 in growing calves, and in recent experiments the ratio of ME to DE was reported to range from 0.89 to 0.94 (Hales et al., 2012, 2013, 2014, 2015a,b). The disparity between these data and the NRC (2000) could be caused by many factors, but the most likely is the level of dietary fat in recent feedlot diets vs. diets that were used when the 80% ratio was quantified. It is well documented that the adding dietary fat can reduce methane in high-concentrate feedlot diets (Boadi et al., 2013, 2016).

There is no data evaluating energy balance when fat is titrated in a high-concentrate finishing diets. The objectives of our experiment were to determine if adding dietary fat increased the ME:DE ratio and quantify energy and nutrient balance in finishing beef steers.

**MATERIALS AND METHODS**

All animal use protocols were approved by the U.S. Meat Animal Research Center (MARC) Animal Care and Use Committee. Angus steers (n = 8; 397 ± 4 kg of initial BW) were used in the experiment. The experiment was conducted between February and mid-May of 2014. The steers were born in spring of 2013 and weaned between September 1 and September 25, 2013. Before the start of the experiment, the steers vaccinated with Bovi-Shield Gold 5 (Zoetis, Pasippany, NJ) and were implanted with Revalor XS (200 mg trenbolone acetate and 40 mg of estradiol 17β; Merck Animal Health, DeSoto, KS). During diet adaptation, steers were housed in 4 partially covered soil-surface pens open to the south. During collections, were moved to a metabolism facility where they were housed in individual stalls (87 cm × 214 cm) equipped with automatic, individual water cups. Before the start of the experiment, cattle were adapted to close human contact in the barn for at least 6 wk. During this time, steers were trained to wear fecal bags and urine harnesses and use the head-boxes. After adaptation to the collection facility, the steers were stratified by BW and randomly assigned to 1 of 2 Latin square replicates 8 steers (replicated 4 × 4 Latin squares). For blood and rumen fluid metabolites, there were 3 Latin square replicates (n = 12 total steers, using an additional 4 steers than for the energy and nutrient balance collections), and the cattle in the third Latin square replicate were the same breed, BW, and age as the other steers used in the energy and nutrient balance study. Each of the 4 periods in the Latin square consisted of an initial 16-d diet adaptation and 5 d of fecal and urine collections, resulting in a total of 84 d for the experiment.

Cattle were fed once daily at 0700 h throughout the experiment and had ad libitum access to feed. Steers had access to fresh water at all times. During the collection periods, orts were weighed daily 24 h after feeding the day before and a subsample was saved for later determination of DM content and GE determination. The dietary treatments (Table 1) consisted of: (1) 0% added corn oil (Fat-0); (2) 2% added corn oil (Fat-2); (3) 4% added corn oil (Fat-4); and (4) 6% added corn oil (Fat-6). Corn oil replaced dry-rolled corn (DRC) on a DM basis. Rumensin 90 (33 mg/kg; Elanco Animal Health, Greenfield, IN) and vitamins and minerals to exceed NRC (2000) requirements were incorporated into a commercial supplement premix. Based on NRC (2000) equations.

| Item                  | Fat-0 | Fat-2 | Fat-4 | Fat-6 |
|----------------------|------|------|------|------|
| Dry-rolled corn, %    | 81.30| 79.00| 76.75| 74.55|
| Alfalfa hay, %        | 10.00| 10.00| 10.00| 10.00|
| Corn oil, %           | 2.00 | 4.00 | 6.00 | 6.00 |
| Soybean meal, %       | 5.00 | 5.25 | 5.45 | 5.45 |
| Urea, %               | 0.50 | 0.50 | 0.50 | 0.50 |
| Supplement, %         | 3.50 | 3.50 | 3.50 | 3.50 |
| Dry matter, %         | 90.41| 90.60| 90.79| 90.98|
| CP, %                 | 15.02| 15.02| 15.02| 15.09|
| Starch, %             | 56.85| 54.50| 52.60| 51.45|
| NDF, %                | 13.87| 13.46| 13.23| 13.23|
| Ether extract, %      | 3.00 | 5.61 | 7.72 | 8.71 |
| Ca, %                 | 0.70 | 0.69 | 0.70 | 0.69 |
| P, %                  | 0.34 | 0.35 | 0.35 | 0.32 |
| NEm, Mcal/kg          | 2.04 | 2.09 | 2.14 | 2.19 |
| NEg, Mcal/kg          | 1.40 | 1.44 | 1.47 | 1.51 |

1Diets were based on dry-rolled corn (DRC) and corn oil was added at 0% (Fat-0), 2% (Fat-2), 4% (Fat-4), and 6% (Fat-6) replacing DRC on a DM basis.

2Rumensin 90 (33 mg/kg; Elanco Animal Health, Greenfield, IN) and including dry-rolled corn as the base ingredient; as that is the predominant type of concentrate grain available at MARC. Alfalfa hay was chosen as the roughage source, as it is grown at MARC and harvested at mid-bloom and generally the quality is consistent. Corn oil was chosen as it was logistically difficult to procure less than a semi-truck of tallow or yellow grease. Urea was used to ensure the diets were approximately isonitrogenous. The corn oil inclusion was decided based on levels currently used in.
the feedlot industry. The inclusion of 6% of DM was chosen because ruminants fed high-concentrate diets can receive up to 6% added dietary fat without negative effects on growth performance (NRC, 2016). By design, the diets were isonitrogenous and contained approximately 15% CP. Starch decreased as corn oil replaced DRC in the diets as starch was displaced when DRC decreased. Similarly, NDF decreased as corn oil increased in the diet. As expected, ether extract increased as corn oil increased in the diet from 0% to 6% of DM. Calcium and phosphorus were approximately similar across diets, and NE\textsubscript{m} and NE\textsubscript{g} increased as corn oil replaced dry-rolled corn.

Diets, orts, urine, and feces were weighed daily. Orts, feces, and urine were collected after every 24 h. Urine was collected using a rubber mold that was attached to the animal using a harness. The rubber mold was placed under the animal’s sheath with tubing which connected it to a polypropylene jug under vacuum where each jug contained 100 mL of 3.6 N HCl to prevent ammonia losses. Feces were collected in a canvas bag attached to a harness. Three percent of urine and feces were collected daily, thoroughly mixed, and pooled within steer and stored at −20°C for later laboratory analyses.

Treatment diets were mixed in 150-kg batches 2 times per wk in a small stationary mixer (H.C. Davis Sons Manufacturing Co., Inc., Bonner Springs, KS) and stored in feed carts. Ingredients were added to the mixer and each diet was allowed to mix for approximately 10 min. Cleanout of the mixer unit was performed to ensure that no cross-contamination of diets occurred.

Composited diet, orts, and fecal samples were dried for 48 h in a forced-air oven at 55°C. Samples were then ground through a Wiley Mill (Arthur Thomas Co., Philadelphia, PA) to pass through a 1-mm screen. Gross energy was measured via bomb calorimetry for dried diets, orts, feces, and freeze-dried urine. Neutral detergent fiber content was measured on dried diets and fecal samples by placing the sample in an individual Ankom fiber bag (F57 Filter Bags; Ankom Technology, Macedon, NY) that was heat sealed. The NDF analysis was performed with an Ankom 200 Fiber Analyzer (Ankom Technology) following the procedures of Van Soest et al. (1991). Heat-stable α-amylase and sodium sulfite (1 g/100 mL of NDF solution) were added to the solution during the analysis. The bags containing the residual were then dried for 24 h at 100°C in a forced-air oven for quantification of the NDF residue. Ether extract was quantified by refluxing ether over samples in Soxhlet tubes for 18 h. Diet and fecal N was quantified by a commercial laboratory (Servi-Tech Labs, Hastings, NE) using the Kjeldahl method.

Following each collection period, O\textsubscript{2}, CO\textsubscript{2}, and CH\textsubscript{4} gases were measured by indirect calorimetry using 8 portable respiration head boxes for 24 h using the procedure has been previously reported by Hales et al. (2014). At least 3 air turnovers were allowed before the gas measurements were determined. The animal’s daily diet allotment was placed in each box before gas collections began, and the cattle consumed > 85% of the feed offered. Gas exchange was determined by pulling air through the box across a temperature-compensated dry test meter to determine airflow leaving the box. Real-time air temperature and humidity were determined. Proportional samples of background air entering the box and air exhausted from the box were collected in polyethylene-aluminum-Mylar laminate gas bags to form a composite air sample for the collection period for each individual box. Gas samples were analyzed for O\textsubscript{2}, CO\textsubscript{2}, and CH\textsubscript{4} according to Nienaber and Maddy (1985). Heat production (HP) was calculated using the Brouwer equation (Brouwer, 1965). Before gas measurements were collected, each head box was calibrated for O\textsubscript{2} consumed and CO\textsubscript{2} produced by burning absolute ethanol with alcohol lamps. Recoveries ranged from 98% to 101% in all head boxes. Energy retained as protein was calculated assuming a N content of 17% for meat protein and a caloric content of 5.7 Mcal/kg of protein (Kleiber, 1975). Tissue energy retained as protein equaled N retained multiplied by 5.88 g of protein/g of N multiplied by 5.7 kcal/g of protein. Tissue energy retained as fat and carbohydrate was equal to recovered energy less recovered energy as protein.

On d 14 of each period, blood (10 mL) was collected via jugular venipuncture into tubes containing EDTA (1.7 µg/mL of blood) and placed on ice immediately prior to feeding (prefeeding) and 4-h postfeeding. Blood samples were then centrifuged at 3,000 × g for 25 min at 4°C to obtain plasma. On the day of collection, glucose and l-lactate were quantified using an immobilized enzyme system (YSI model 2700; YSI Inc., Yellow Spring, OH). Separate aliquots were stored at −20°C. Nonesterified fatty acids were quantified using a colorimetric assay according to manufacturer’s procedures (Zen-Bio Inc., Research Triangle Park, NC). Plasma was also analyzed for β-hydroxybutyrate (BHBA) using the method of Williamson and Mellanby (1965) modified for use in a 96-well plate.

A sample of rumen fluid was aspirated via a stomach tube 4-h postfeeding. Rumen fluid was strained through 4 layers of cheesecloth and placed on ice. On the same day of collection, l-lactate was quantified using an immobilized enzyme system (YSI model 2700; YSI Inc.). Ammonia was quantified using the hypochlorite method (McCullough, 1967) modified for use...
in a 96-well plate. Rumen fluid was analyzed for VFA using the methods described by Foote et al. (2013).

All data were analyzed as a Latin square design using the Mixed procedure of SAS (SAS Inst. Inc., Cary, NC). The model included fixed effects of dietary treatment (corn oil inclusion). The model also included the random effects of square and steer within square. Orthogonal contrast statements were used to evaluate linear and quadratic effects of corn oil inclusion. For ruminal ammonia, plasma NEFA, and plasma lactate, values were log base 10 transformed to achieve near normality, as indicated by a Shapiro-Wilk statistic ($W > 0.95$). Effects were considered significant at $P$-value of $≤ 0.05$, with tendencies discussed at $P$-values between 0.05 and 0.10.

**RESULTS**

Dry matter intake did not differ as corn oil increased in the diet ($P ≥ 0.39$; Table 2); nor did GE intake differ ($P ≥ 0.63$). Fecal energy loss (megacalories or as a proportion of GE intake) was not different as corn oil increased from 0 to 6% of dietary DM ($P ≥ 0.22$). Furthermore, DE did not differ across diet ($P ≥ 0.27$) when corn oil replaced DRC. Megacalories of urinary energy did not differ as corn oil increased in the diet ($P ≥ 0.69$). Additionally, urinary energy loss as a proportion of GE intake was not different across treatment ($P ≥ 0.56$).

Megalcalories of methane energy decreased linearly as corn oil increased from 0% to 6% of diet DM ($P < 0.01$; Table 2). Likewise, methane energy loss as a proportion of GE intake decreased linearly by 34% as corn oil replaced DRC in the diet ($P < 0.01$). Moreover, ME was not different across diet ($P ≥ 0.87$). However, the ME-to-DE ratio increased linearly from 93.06% to 95.20% as corn oil increased in the diet ($P < 0.01$).

Megalcalories of heat production did not differ across diet ($P ≥ 0.23$; Table 2), nor did heat production as a proportion of GE intake ($P ≥ 0.51$). No differences were detected for megacalories of RE ($P ≥ 0.67$) or RE as a proportion of GE intake ($P ≥ 0.64$).

Megalcalories of RE as protein decreased linearly as corn oil increased in the diet (Table 3; $P < 0.01$). As a proportion of GE intake, RE as protein decreased linearly as corn oil was increased in the diet ($P < 0.01$). As a proportion of total energy retained, RE as protein decreased when corn oil increased from 0 to 6% of diet DM ($P < 0.01$). Megacalories of RE as fat and carbohydrate tended to increase ($P = 0.10$) as corn oil increased and replaced DRC in the diet. Similarly, RE as fat and carbohydrate as a proportion of GE intake, increased linearly as corn oil increased in the diet ($P = 0.05$). Additionally, RE as fat and carbohydrate as a proportion of total energy retained increased linearly as corn oil increased from 0 to 6% of diet DM ($P < 0.01$).

Nitrogen intake did not differ across dietary treatments ($P ≥ 0.26$; Table 4). Urinary N excretion (g/d)

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### Table 2. Influence of feeding dry-rolled corn-based diets with 0%, 2%, 4%, and 6% added corn oil on daily energy partitioning in finishing beef steers fed at ad libitum intake

| Item                                           | Treatment | SEM² | Linear³ | Quadratic³ |
|------------------------------------------------|-----------|------|---------|------------|
| DMI, g                                         | Fat-0     | 7232 | 0.39    | 0.79       |
|                                               | Fat-2     | 7319 |         |            |
|                                               | Fat-4     | 6993 |         |            |
|                                               | Fat-6     | 6898 |         |            |
| GE intake, Mcal                               | Fat-0     | 31.80| 2.849   | 0.74       |
|                                               | Fat-2     | 33.26| 0.63    |            |
|                                               | Fat-4     | 32.64|         |            |
|                                               | Fat-6     | 33.10|         |            |
| Fecal energy, Mcal                           | Fat-0     | 8.53 | 0.822   | 0.66       |
|                                               | Fat-2     | 9.06 | 0.22    |            |
|                                               | Fat-4     | 9.29 |         |            |
|                                               | Fat-6     | 9.38 |         |            |
| Fecal energy loss, % of GE intake            | Fat-0     | 26.83| 1.079   | 0.87       |
|                                               | Fat-2     | 27.34| 0.27    |            |
|                                               | Fat-4     | 28.18|         |            |
|                                               | Fat-6     | 28.35|         |            |
| Digestible energy intake, Mcal               | Fat-0     | 23.27| 2.130   | 0.83       |
|                                               | Fat-2     | 24.20| 0.92    |            |
|                                               | Fat-4     | 23.35|         |            |
|                                               | Fat-6     | 23.72|         |            |
| Digestible energy                            | Fat-0     | 73.17| 1.802   | 0.87       |
|                                               | Fat-2     | 72.66| 0.55    |            |
|                                               | Fat-4     | 71.81|         |            |
|                                               | Fat-6     | 71.65|         |            |
| Urinary energy, Mcal                         | Fat-0     | 0.47 | 0.064   | 0.69       |
|                                               | Fat-2     | 0.42 | 0.99    |            |
|                                               | Fat-4     | 0.47 |         |            |
|                                               | Fat-6     | 0.42 |         |            |
| Urinary energy loss, % of GE intake          | Fat-0     | 1.52 | 0.204   | 0.87       |
|                                               | Fat-2     | 1.28 | 0.56    |            |
|                                               | Fat-4     | 1.48 |         |            |
|                                               | Fat-6     | 1.30 |         |            |
| Methane energy, Mcal                         | Fat-0     | 1.06 | 0.098   | 0.99       |
|                                               | Fat-2     | 1.00 | 0.01    |            |
|                                               | Fat-4     | 0.78 |         |            |
|                                               | Fat-6     | 0.73 |         |            |
| Methane energy, % of GE intake               | Fat-0     | 3.39 | 0.375   | < 0.01     |
|                                               | Fat-2     | 3.00 | > 0.01  |            |
|                                               | Fat-4     | 2.35 |         |            |
|                                               | Fat-6     | 2.23 |         |            |
| Metabolizable energy intake, Mcal            | Fat-0     | 21.74| 2.107   | 0.82       |
|                                               | Fat-2     | 22.77| 0.73    |            |
|                                               | Fat-4     | 22.10|         |            |
|                                               | Fat-6     | 22.57|         |            |
| Metabolizable energy                         | Fat-0     | 68.26| 1.163   | 0.99       |
|                                               | Fat-2     | 68.37| 0.87    |            |
|                                               | Fat-4     | 67.98|         |            |
|                                               | Fat-6     | 68.12|         |            |
| ME:DE                                         | Fat-0     | 93.06| 0.872   | < 0.01     |
|                                               | Fat-2     | 94.10| < 0.01  |            |
|                                               | Fat-4     | 94.64|         |            |
|                                               | Fat-6     | 95.20|         |            |
| Heat production, Mcal                        | Fat-0     | 15.90| 0.824   | 0.23       |
|                                               | Fat-2     | 16.94| 0.55    |            |
|                                               | Fat-4     | 16.71|         |            |
|                                               | Fat-6     | 16.45|         |            |
| Heat production, % of GE intake              | Fat-0     | 50.75| 2.376   | 0.51       |
|                                               | Fat-2     | 51.02| 0.90    |            |
|                                               | Fat-4     | 51.78|         |            |
|                                               | Fat-6     | 50.25|         |            |
| Recovered energy, Mcal                       | Fat-0     | 5.84 | 1.357   | 0.67       |
|                                               | Fat-2     | 5.83 | 0.92    |            |
|                                               | Fat-4     | 5.38 |         |            |
|                                               | Fat-6     | 6.12 |         |            |
| Recovered energy, % of GE intake             | Fat-0     | 17.51| 2.835   | 0.64       |
|                                               | Fat-2     | 17.35| 0.99    |            |
|                                               | Fat-4     | 16.20|         |            |
|                                               | Fat-6     | 17.87|         |            |

1Diets were based on dry-rolled corn (DRC) and corn oil was added at 0% (Fat-0), 2% (Fat-2), 4% (Fat-4), and 6% (Fat-6) replacing DRC on a DM basis.
2Pooled standard error of least squares means ($n = 8$).
3Observed significance levels for treatment comparisons.
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In contrast, fecal N excretion increased linearly as corn oil inclusion increased in the diet and decreased linearly in the feces ($P < 0.01$). Additionally, excretion of N as a proportion of N intake increased linearly in the urine ($P < 0.01$) and was not different in the feces ($P = 0.35$). Apparent N digested (g/d or % of N intake) was not different as corn oil increased in the diet ($P ≥ 0.35$). Grams of N retained did not differ as corn oil increased in the diet.

Table 3. Influence of feeding dry-rolled corn-based diets with 0%, 2%, 4%, and 6% added corn oil on energy partitioning in finishing beef steers fed at ad libitum intake on the partitioning of protein, fat, and carbohydrate in finishing steers fed at ad libitum intake.

| Item                                                                 | Treatment | SEM2 | $P$-value |
|----------------------------------------------------------------------|-----------|------|-----------|
| Recovered energy as protein, Mcal4                                     | Fat-0     | 3.23 | < 0.01    |
| Recovered energy as protein, % of GE intake4                           | Fat-2     | 3.01 | 0.54      |
| Recovered energy as protein, % of total energy recovered4              | Fat-4     | 2.62 | < 0.01    |
| Recovered energy as protein, % of total energy recovered4              | Fat-6     | 1.95 | 0.58      |
| Recovered energy as fat and carbohydrate, Mcal5                        | Fat-0     | 67.32| < 0.01    |
| Recovered energy as fat and carbohydrate, % of GE intake5              | Fat-2     | 55.37| < 0.01    |
| Recovered energy as fat and carbohydrate, % of total energy recovered5 | Fat-4     | 51.67| 0.10      |
| Recovered energy as fat and carbohydrate, % of total energy recovered5 | Fat-6     | 32.68| 0.05      |

1Diets were based on dry-rolled corn (DRC) and corn oil was added at 0% (Fat-0), 2% (Fat-2), 4% (Fat-4), and 6% (Fat-6) replacing DRC on a DM basis.

2Pooled standard error of least squares means ($n = 8$).

3Observed significance levels for treatment comparisons.

4Energy retained as protein was calculated assuming a N content of 17% for meat protein and a caloric content of 5.7 Mcal/kg of protein (Kleiber, 1975). Meat protein was estimated using the retained protein values measured in the balance study. Tissue energy retained as protein = N retained $\times$ 5.88 g of protein/g of N $\times$ 5.7 kcal/g of protein.

5Tissue energy retained as fat and carbohydrate = recovered energy – recovered energy as protein.

Table 4. Influence of feeding dry-rolled corn-based diets with 0%, 2%, 4%, and 6% added corn oil on nitrogen balance in finishing beef steers fed at ad libitum intake.

| Item                                                                 | Treatment | SEM2 | $P$-value |
|----------------------------------------------------------------------|-----------|------|-----------|
| N intake, g/d                                                        | Fat-0     | 173.41| 0.26      |
| N excretion, g/d                                                     | Fat-2     | 173.96| 0.81      |
| Urine                                                               | Fat-4     | 165.78|           |
| Feces                                                               | Fat-6     | 162.43|           |
| Total                                                               |           | 14.84 |           |
| N excretion, % of total N excretion                                  |           | 0.26  |           |
| Urine                                                               |           | 0.81  |           |
| Feces                                                               |           | 0.26  |           |
| Total                                                               |           | 0.81  |           |
| N excretion, % of N intake                                          |           | 0.26  |           |
| Urine                                                               |           | 0.81  |           |
| Feces                                                               |           | 0.26  |           |
| Apparent N digested (g/d)                                            |           | 0.26  |           |
| % of N intake                                                       |           | 0.81  |           |
| N retained g/d                                                       |           | 0.26  |           |
| % of N intake                                                       |           | 0.81  |           |

1Diets were based on dry-rolled corn (DRC) and corn oil was added at 0% (Fat-0), 2% (Fat-2), 4% (Fat-4), and 6% (Fat-6) replacing DRC on a DM basis.

2Pooled standard error of least squares means ($n = 8$).

3Observed significance levels for treatment comparisons.
because of treatment ($P \geq 0.25$); however, N retained as a proportion of N intake decreased linearly as corn oil increased in the diet ($P < 0.01$).

Dry matter digestibility did not differ as corn oil inclusion was increased in the diet ($P \geq 0.36$; Table 5). Neutral detergent fiber intake tended to decrease linearly as corn oil increased in the diet ($P = 0.10$); however, there were no differences in fecal excretion and digestibility of NDF ($P \leq 0.26$). Starch intake decreased linearly ($P = 0.05$) as corn oil increased in the diet. No differences were detected in fecal excretion or digestibility of starch ($P \geq 0.18$).

Ether extract intake responded quadratically in that it increased from 0 to 2% corn oil in the diet then reached a plateau at 4% corn oil inclusion ($P < 0.01$). Furthermore, fecal excretion of ether extract increased linearly as corn oil increased in the diet ($P = 0.05$); whereas, digestibility of ether extract tended to respond quadratically in that it increased from 0 to 2% corn oil inclusion and reached a plateau at 4% corn oil inclusion ($P < 0.01$). Additionally, OM intake tended to decrease linearly as corn oil increased in the diet ($P = 0.09$), no other differences in OM fecal excretion or digestibility were detected ($P \geq 0.35$).

Concentrations of ruminal total VFA were not affected by dietary treatment ($P \geq 0.25$; Table 6). There was a tendency for a quadratic response in isobutyrate concentrations ($P = 0.08$) where concentrations were greater for the Fat-2 and Fat-4 treatments than the Fat-0 and Fat-6 treatments. A similar result was observed for ruminal lactate concentration ($P = 0.05$), where concentrations were increased with the Fat-2 and Fat-4 treatments. Ruminal ammonia concentrations tended to increase linearly with increasing dietary fat concentrations ($P = 0.07$).

There was a tendency for a linear response ($P = 0.08$) in plasma prefeeding NEFA concentrations, where NEFA concentrations increased with increasing dietary fat. There was also a tendency ($P = 0.10$) for a quadratic response in prefeeding plasma BHBA concentrations, indicating that BHBA concentrations were slightly greater with the 2% and 4% inclusion of fat in the diet compared to 0% and 6% fat inclusion. Postfeeding plasma lactate linearly decreased ($P = 0.03$) and plasma NEFA linearly increased ($P = 0.01$) with increasing concentrations of dietary fat. Postfeeding plasma BHBA tended to respond quadratically ($P = 0.10$), with the concentrations increasing with the 2% and 4% fat inclusion compared to the 0% and 6% fat inclusion. There was a linear response to dietary fat concentrations in the change (delta) of plasma lactate concentrations from prefeeding to postfeeding ($P = 0.04$), where lactate concentrations increased for the Fat-0 and Fat-2 by decreased for the Fat-4 and Fat-6 treatments in response to feeding. The change in plasma NEFA tended ($P = 0.08$) to respond linearly with

Table 5. Influence of feeding dry-rolled corn-based diets with 0%, 2%, 4%, and 6% added corn oil on digestibility in finishing beef steers fed at ad libitum intake

| Item                      | Treatment | SEM$^2$ | P-value  |
|---------------------------|-----------|---------|----------|
| Dry matter digestibility, % DMI | Fat-0     | 74.87   |          |
|                           | Fat-2     | 74.66   |          |
|                           | Fat-4     | 74.56   |          |
|                           | Fat-6     | 73.57   |          |
|                           | SEM       | 0.981   |          |
|                           | Linear$^3$| 0.36    | 0.69     |
|                           | Quadratic$^3$| < 0.01 |          |
| NDF Intake, g/d           | Fat-0     | 997.27  |          |
|                           | Fat-2     | 988.47  |          |
|                           | Fat-4     | 927.26  |          |
|                           | Fat-6     | 880.69  |          |
|                           | SEM       | 96.989  |          |
|                           | Linear$^3$| 0.10    | 0.75     |
|                           | Quadratic$^3$| < 0.01 |          |
| Fecal excretion, g/d      | Fat-0     | 495.03  |          |
|                           | Fat-2     | 491.22  |          |
|                           | Fat-4     | 447.78  |          |
|                           | Fat-6     | 481.52  |          |
|                           | SEM       | 55.438  |          |
|                           | Linear$^3$| 0.35    | 0.35     |
|                           | Quadratic$^3$| < 0.01 |          |
| Digestibility, % of intake| Fat-0     | 49.73   |          |
|                           | Fat-2     | 49.03   |          |
|                           | Fat-4     | 51.24   |          |
|                           | Fat-6     | 44.78   |          |
|                           | SEM       | 2.616   |          |
|                           | Linear$^3$| 0.26    | 0.26     |
| Starch Intake, g/d        | Fat-0     | 4114.03 |          |
|                           | Fat-2     | 3996.52 |          |
|                           | Fat-4     | 3678.16 |          |
|                           | Fat-6     | 3546.54 |          |
|                           | SEM       | 356.43  |          |
|                           | Linear$^3$| 0.05    | 0.97     |
|                           | Quadratic$^3$| < 0.01 |          |
| Fecal excretion, g/d      | Fat-0     | 397.14  |          |
|                           | Fat-2     | 384.63  |          |
|                           | Fat-4     | 402.41  |          |
|                           | Fat-6     | 390.02  |          |
|                           | SEM       | 40.730  |          |
|                           | Linear$^3$| 0.98    | 0.99     |
|                           | Quadratic$^3$| < 0.01 |          |
| Digestibility, % of intake| Fat-0     | 90.46   |          |
|                           | Fat-2     | 90.07   |          |
|                           | Fat-4     | 89.29   |          |
|                           | Fat-6     | 89.19   |          |
|                           | SEM       | 0.835   |          |
|                           | Linear$^3$| 0.18    | 0.85     |
| Ether Extract Intake, g/d | Fat-0     | 209.18  |          |
|                           | Fat-2     | 410.98  |          |
|                           | Fat-4     | 537.86  |          |
|                           | Fat-6     | 597.34  |          |
|                           | SEM       | 28.78   |          |
|                           | Linear$^3$| < 0.01  | < 0.01   |
| Digestibility, % of intake| Fat-0     | 42.33   |          |
|                           | Fat-2     | 53.91   |          |
|                           | Fat-4     | 53.19   |          |
|                           | Fat-6     | 58.41   |          |
|                           | SEM       | 8.580   |          |
|                           | Linear$^3$| 0.05    | 0.58     |
| Organic Matter Intake, g/d| Fat-0     | 7228.14 |          |
|                           | Fat-2     | 7315.05 |          |
|                           | Fat-4     | 6989.42 |          |
|                           | Fat-6     | 6893.76 |          |
|                           | SEM       | 644.2   |          |
|                           | Linear$^3$| 0.09    | 0.79     |
| Fecal excretion, g/d      | Fat-0     | 1817.31 |          |
|                           | Fat-2     | 1845.78 |          |
|                           | Fat-4     | 1786.73 |          |
|                           | Fat-6     | 1823.86 |          |
|                           | SEM       | 191.87  |          |
|                           | Linear$^3$| 0.92    | 0.96     |
| Digestibility, % of intake| Fat-0     | 74.88   |          |
|                           | Fat-2     | 74.66   |          |
|                           | Fat-4     | 74.57   |          |
|                           | Fat-6     | 73.58   |          |
|                           | SEM       | 0.981   |          |
|                           | Linear$^3$| 0.35    | 0.69     |
|                           | Quadratic$^3$| < 0.01 |          |

1Diets were based on dry-rolled corn (DRC) and corn oil was added at 0% (Fat-0), 2% (Fat-2), 4% (Fat-4), and 6% (Fat-6) replacing DRC on a DM basis.

2Pooled standard error of least squares means ($n = 8$).

3Observed significance levels for treatment comparisons.
Increasing fat in feedlot diets

Cattle fed high-concentrate finishing diets and allowed adequate adaptation to fat in the diet can receive up to 6% supplemental fat without adverse effects on growth performance (Zinn and Jorquera, 2007). In contrast, Zinn and Shen (1996) reported that supplemental fat in the form of yellow grease at 5% of DM decreased DMI in crossbred steers fed for 84 d. Additionally, the nutrient requirements of beef cattle (NRC, 2016) and dairy cattle NRC (2001) recommends that fat should not be fed greater than 7% of the dietary DM or a depression in feed intake can occur. Thus, the lack of differences in fecal energy loss and DE are not surprising as supplemental fat less than 8% of DM rarely has an effect on digestibility of starch or N (Zinn, 1988; 1989), even though the total fat in the 6% added corn oil diet was 8.7% of DM. Because the diets were formulated to be isonitrogenous, no differences in urinary energy losses were expected, as the majority of the energy in urine comes from N.

The decrease in megacalories of methane and methane as a proportion of GE intake was expected as it has been well documented that added dietary fat inclusion, which indicated that increasing fat concentrations corresponded to greater increases in plasma NEFA concentrations in response to feeding.

**DISCUSSION**

Cattle fed high-concentrate finishing diets and allowed adequate adaptation to fat in the diet can receive up to 6% supplemental fat without adverse effects on growth performance (Zinn and Jorquera, 2007). In contrast, Zinn and Shen (1996) reported that supplemental fat in the form of yellow grease at 5% of DM decreased DMI in crossbred steers fed for 84 d. Additionally, the nutrient requirements of beef cattle (NRC, 2016) and dairy cattle NRC (2001) recommends that fat should not be fed greater than 7% of the dietary DM or a depression in feed intake can occur. Thus, the lack of differences in fecal energy loss and DE are not surprising as supplemental fat less than 8% of DM rarely has an effect on digestibility of starch or N (Zinn, 1988; 1989), even though the total fat in the 6% added corn oil diet was 8.7% of DM. Because the diets were formulated to be isonitrogenous, no differences in urinary energy losses were expected, as the majority of the energy in urine comes from N.

The decrease in megacalories of methane and methane as a proportion of GE intake was expected as it has been well documented that added dietary fat

### Table 6. Influence of feeding dry-rolled corn-based diets with 0%, 2%, 4%, and 6% added corn oil on digestibility and blood metabolites (all concentrations expressed in mM, except NEFA are expressed in μEq/L) in finishing beef steers fed at ad libitum intake

| Item               | Treatment | SEM² | P-Value | Linear¹ | Quadratic³ |
|--------------------|-----------|------|---------|---------|------------|
| **Rumen Fluid**    |           |      |         |         |            |
| Total VFA          | Fat-0     | 129.3| 139.1   | 140.0   | 130.1      | 8.73       | 0.93 | 0.25 |
| Acetate            | Fat-2     | 60.4 | 66.4    | 65.7    | 62.4       | 4.07       | 0.79 | 0.24 |
| Propionate         | Fat-4     | 55.8 | 57.5    | 58.8    | 54.3       | 4.62       | 0.88 | 0.50 |
| Butyrate           | Fat-6     | 7.76 | 9.59    | 9.99    | 9.05       | 1.09       | 0.32 | 0.15 |
| Isobutyrate        |           | 0.68 | 0.79    | 0.80    | 0.64       | 0.097      | 0.76 | 0.08 |
| Isovalerate        |           | 2.10 | 2.58    | 1.50    | 1.40       | 0.55       | 0.21 | 0.61 |
| Valerate           |           | 2.56 | 2.22    | 3.07    | 2.22       | 0.32       | 0.90 | 0.35 |
| Lactate            |           | 0.210| 0.286   | 0.252   | 0.225      | 0.031      | 0.93 | 0.05 |
| Log Ammonia        |           | 0.37 | 0.50    | 0.65    | 0.58       | 0.12       | 0.07 | 0.30 |
| Ammonia            |           | 2.32 | 3.17    | 4.48    | 3.84       | .          | .    | .    |
| **Prefeeding Plasma** |          |      |         |         |            |
| Glucose            | Fat-0     | 5.52 | 5.43    | 5.58    | 5.14       | 0.16       | 0.88 | 0.53 |
| Log Lactate        | Fat-2     | 0.42 | 0.38    | 0.42    | 0.48       | 0.070      | 0.25 | 0.19 |
| Lactate            | Fat-4     | 2.65 | 2.40    | 2.60    | 3.05       | .          | .    | .    |
| Log NEFA           | Fat-6     | 1.12 | 1.20    | 1.16    | 1.23       | 0.040      | 0.08 | 0.83 |
| NEFA               |           | 13.2 | 15.9    | 14.5    | 17.0       | .          | .    | .    |
| BHBA²              |           | 0.35 | 0.40    | 0.39    | 0.34       | 0.044      | 0.89 | 0.10 |
| **Postfeeding Plasma** |        |      |         |         |            |
| Glucose            | Fat-0     | 5.58 | 5.74    | 5.54    | 5.82       | 0.20       | 0.35 | 0.64 |
| Log Lactate        | Fat-2     | 0.52 | 0.48    | 0.39    | 0.38       | 0.062      | 0.03 | 0.79 |
| Lactate            | Fat-4     | 3.27 | 3.03    | 2.46    | 2.42       | .          | .    | .    |
| Log NEFA           | Fat-6     | 1.19 | 1.23    | 1.26    | 1.34       | 0.041      | 0.01 | 0.70 |
| NEFA               |           | 15.4 | 17.2    | 18.3    | 21.9       | .          | .    | .    |
| BHBA²              |           | 0.34 | 0.42    | 0.40    | 0.38       | 0.042      | 0.44 | 0.10 |
| **Delta**          |           |      |         |         |            |
| Glucose            | Fat-0     | 0.05 | 0.20    | 0.11    | 0.24       | 0.17       | 0.51 | 0.98 |
| Lactate            | Fat-2     | 0.48 | 0.81    | −0.18   | −0.80      | 0.50       | 0.04 | 0.35 |
| NEFA               | Fat-4     | 1.98 | 1.42    | 3.59    | 4.89       | 1.36       | 0.08 | 0.50 |
| BHBA²              | Fat-6     | −0.008| 0.015  | 0.009   | 0.036      | 0.024      | 0.19 | 0.93 |

¹Diets were based on dry-rolled corn (DRC) and corn oil was added at 0% (Fat-0), 2% (Fat-2), 4% (Fat-4), and 6% (Fat-6) replacing DRC on a DM basis.

²Pooled standard error of least squares means (n = 12).

³Observed significance levels for treatment comparisons.

⁴Values were log (base 10) transformed to achieve normality. Back-transformed means are presented in the lines below the transformed data.

⁵Beta-hydroxybutyrate.
decreases enteric methane production (Johnson and Johnson, 1995; McGinn et al., 2004; Beauchemin et al., 2007). Beauchemin et al. (2007) reviewed the literature and calculated that for livestock ruminants (beef cattle, dairy cattle, and sheep) methane production decreased 5.6% for every 1% increase in added dietary fat. Added dietary fat typically decreases enteric methane through 3 mechanisms: providing a hydrogen sink through biohydrogenation, increased propionate production, and replacing less fermentable substrates that would increase methane production (Nagaraja et al., 1997). Additionally, the loss of methane as a proportion of GE intake ranged from 2.23 to 3.39% which is consistent with other studies using high-concentrate finishing diets (Hales et al., 2012; 2013; 2014; 2015a). In this study, ruminal propionate concentrations were not increased with increasing dietary fat, which indicates that the observed reduction in methane production was likely due to biohydrogenation sequestering hydrogen, a decrease in fermentable substrate due to substitution of oil for corn, or direct inhibition of protozoa by the corn oil. If fermentable substrate reduction was a major factor, there would likely have been an observed reduction in total ruminal VFA concentrations, and likely a decrease in plasma BHBA. Because there was no reduction in fermentable substrate, the methane reduction observed was likely caused by biohydrogenation of the added dietary corn oil. However, the observed reduction in the change in plasma lactate concentrations relative to feeding would indicate that there may have been a decrease in ruminal lactate production with 4% and 6% fat inclusion, which would mostly be derived from starch digestion.

The increase in the ME:DE ratio was expected, and it was the authors’ hypothesis that the ratio would increase with added dietary fat. According to the beef cattle NRC (2000), the ratio of ME to DE is approximately 80% but can vary according to intake, age of animal, and feed source. Previously, the beef cattle NRC (1984) used 0.82 as the ME:DE ratio. Thus, approximately 0.8 has been used for several decades. Data summarized by Vermorel and Bickel (1980) reported that the ME:DE ratio ranged from 0.82 to 0.93 in growing cattle and was near 0.81 in adult sheep. Vermorel and Bickel (1980) suggested that high ME:DE ratios could be expected in growing cattle vs. mature cattle because of less methane and urinary energy losses. The cattle used in the present experiment were approximately 11 mo of age at the beginning of the study. Other data generated when feeding high-concentrate finishing diets also support a greater ME:DE ratio than 0.8 (Hales et al., 2012, 2013, 2014, 2015a,b). The ME:DE in the present experiment is greater than values observed previously at this location (Hales et al., 2014; Hales et al., 2015a,b) and is similar to results observed when feeding steam-flaked corn-based diets (Hales et al., 2013). The increased efficiency of DE to ME conversion is thought to be caused by feeding processed grain, added dietary fat, and roughage at less than 10% of DM all of which are known to decrease methane production.

It was not expected that megacalories of heat production or heat production as a proportion of GE intake would differ. Our results agree with a similar experiment at the same location where steers were fed a dry-rolled or combination of a dry-rolled and high-moisture corn-based diet with 25% or 45% WDGS, where no differences in heat production as a proportion of GE intake were noted across treatment (Hales et al., 2015b). Likewise, 2 experiments conducted in Texas with Jersey steers using a steam-flaked corn-based diet with 0%, 15%, 30%, and 45% WDGS (DM-basis; Hales et al., 2013) and feeding a steam-flaked or dry-rolled corn-based diet with 0 or 30% WDGS (DM-basis; Hales et al., 2012) also noted no differences in heat production as a proportion of GE intake across a variety of finishing diets. In contrast, in a study feeding steers 2%, 6%, 10%, and 14% (DM-basis) alfalfa hay, differences in heat production as a proportion of GE intake were reported to respond quadratically, being similar from 2% to 10% alfalfa hay inclusion and increasing to 14% alfalfa hay inclusion. Furthermore, when steers were fed dry-rolled corn-based diet with 0%, 5%, 10%, and 15% glycerin (DM-basis) heat production, as a proportion of GE intake, increased linearly as glycerin increased in the diet (Hales et al., 2015a). It appears that heat production is difficult to change in a metabolism setting (absence of heat stress) in growing cattle because the contribution of maintenance is so great, but it can be increased in response to large dietary changes.

Reasons for the lack of differences could be the decreased intake (although not statistical, but numerical) associated with feeding added corn oil at more than 2% of DM. Hales et al. (2012) reported an increase in RE when Jersey steers were fed steam-flaked vs. dry-rolled corn-based diets, but not when WDGS was fed at 0% or 30% of DM. Similarly, when alfalfa hay was fed to steers at 2%, 6%, 10%, and 14% of DM, RE as a proportion of GE intake decreased linearly as alfalfa hay increased in the diet (Hales et al., 2014) and when WDGS was fed to Jersey steers in a steam-flaked corn-based diet at 0%, 15%, 30%, and 45% of DM RE as a proportion of GE intake decreased linearly. Again, RE seems to be affected most by large dietary changes in which DE is greatly altered.

As expected, RE as protein decreased and energy retained as fat and carbohydrate increased as corn oil
replaced DRC in the diet. Fat supplementation in beef cattle increases the proportion of fat retained in the carcass (NRC, 2016). There is no data currently available on how differing amounts of dietary fat affect energy retained as protein or fat and carbohydrate.

No differences in N intake were anticipated, as the diets were formulated to be isonitrogenous. The increased N excretion in the urine (g of N, excretion as a % of total N excretion and excretion as a % of N intake) was not surprising because presumably microbrial synthesis in the rumen decreased and the added dietary urea was then excreted in the urine. It has been documented that dietary lipids can disrupt the digestion of ruminal proteins (NRC, 2016). Additionally, the tendency for an increase in rumen ammonia concentration with increasing dietary fat could be due to decreased microbial protein synthesis and could partially explain the greater urea loss in the urine. Fats are known to be toxic to ruminal microorganisms through the detergent action of fatty acids on the microbial cell membrane (NRC, 2016) and through inhibition of enzymatic digestion. Furthermore, the decrease in N retained as a proportion of N intake was expected because of the disruption that fat supplementation can have on ruminal protein metabolism (NRC, 2016).

Dissimilar to the present experiment, Zinn and Shen (1996) noted that supplemental fat decreased total tract digestibility of OM and NDF (3% and 20%, respectively). No differences in total tract digestibility of NDF or OM were detected in the present experiment, which was unexpected. Feeding diets high in fat can inhibit fiber digestibility in the rumen (Maczulak et al., 1981; Jenkins, 1993); however, our results do not conform to this trend. It is likely that the diets used in the present experiment were not high enough in NDF to detect a decrease in digestibility when corn oil was added to the diet. Intake of starch decreased by design, as corn oil replaced DRC in the diets. Furthermore, the increase in ether extract intake was also expected, as corn oil replaced DRC in the experimental diets. The NRC (2016) summarized data from 7 studies and reported an inverse linear relationship between fatty acid intake and ruminal lactate in the higher fat diets could indicate a greater reliance on fatty acids for a metabolic fuel than carbohydrates in peripheral tissues, as circulating plasma lactate can be derived from the incomplete oxidation of glucose. It is not likely that these small responses will have large metabolic effects, but a longer term study would be required to determine the effect.

These data indicate that feeding added fat has negative effects on nitrogen retention, but reduces methane production. Additionally, the ratio of ME:DE quantified in this experiment indicates that the common approach in calculating ME from DE data may result in undervaluing concentrate diet components.

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