Finishing performance and diet digestibility for feedlot steers fed corn distillers grains plus solubles and distillers solubles with and without oil extraction¹

M. L. Jolly-Breithaupt, B. L. Nuttelman, C. J. Schneider, D. B. Burken, J. L. Gramkow, A. L. Shreck, J. C. MacDonald, T. J. Klopfenstein, and G. E. Erickson²

Department of Animal Science, University of Nebraska, Lincoln, NE 68583-0908.

ABSTRACT: Three experiments evaluated the effects of corn oil removal using centrifugation in ethanol plants, on animal performance and digestion characteristics by finishing cattle fed by-products. In Exp. 1, 225 crossbred steers (300 ± 9.1 kg) were utilized in a randomized block design with a $2 \times 2 + 1$ factorial arrangement of treatments. Factors consisted of oil concentration [de-oiled (DO) or full fat (FF)] and by-product type [condensed distillers solubles (CDS) or modified distillers grains plus solubles (MDGS)] compared to a corn-based control. Fat concentration was 6.0% for DO CDS, 21.1% for FF CDS, 9.2% for DO MDGS, and 11.8% for FF MDGS. No oil concentration by by-product type interactions ($P \geq 0.17$) were observed. There were no differences in DMI, ADG, or G:F between DO and FF CDS ($P \geq 0.29$) or DO and FF MDGS ($P \geq 0.58$). No differences ($P \geq 0.25$) due to oil concentration were observed for carcass characteristics. Experiment 2 was a 5×5 Latin Square digestion trial with treatments similar to Exp. 1. Fat concentration was 8.7% or 15.4% for DO or FF CDS and 9.2% or 12.3% for DO or FF MDGS. Intake and total tract digestibility of fat were greater ($P \leq 0.02$) for FF CDS compared with DO CDS. Digestible

energy (megacalorie per kilogram), adjusted for intake, was greater ($P = 0.02$) for steers fed FF CDS compared to DO CDS. Average ruminal pH for cattle fed FF MDGS was greater than DO MDGS ($P = 0.06$). In Exp. 3, 336 yearling, crossbred steers (352 ± 19 kg) were utilized in a randomized block design with a $2 \times 3 + 1$ factorial arrangement of treatments. Factors included oil concentration (DO or FF) and inclusion [35%, 50%, and 65% wet distillers grains plus solubles (WDGS)] along with a corn-based control. The fat concentrations of DO and FF WDGS were 7.9% and 12.4%, respectively. A linear interaction ($P < 0.01$) was observed for DMI, which produced different slopes for DO and FF WDGS. No linear or quadratic interactions were observed for BW, ADG, or G:F ($P \geq 0.31$). For the main effect of oil concentration, there were no statistical differences ($P > 0.19$) for final BW, ADG, or G:F. No statistical differences were observed for all carcass traits ($P \geq 0.34$). Corn oil removal via centrifugation had minimal impact on finishing performance suggesting that cattle fed DO by-products will have similar performance to cattle fed FF by-products in dry-rolled and high-moisture corn diets.

Key words: by-products, centrifugation, condensed distillers solubles, corn oil, distillers grains plus solubles, finishing cattle

© The Author(s) 2018. Published by Oxford University Press on behalf of the American Society of Animal Science. All rights reserved. For permissions, please e-mail: journals.permissions@oup.com.

J. Anim. Sci. 2018.96:1996–2011

doi: 10.1093/jas/sky061

¹A contribution of the University of Nebraska-Lincoln Agricultural Research Division, supported in part by funds provided by the Nebraska Corn Board.

²Corresponding author: gerickson4@unl.edu

Received February 16, 2018.

Accepted March 5, 2018.

INTRODUCTION

Distillers grains plus solubles (DGS) is an excellent feedstuff for the cattle industry as DGS are a good source of protein and energy. Typically fed as a protein source, DGS fed at inclusions

greater than 15% to 20% result in excess consumption of protein, which becomes deaminated, and utilized for energy (Klopfenstein et al., 2008). The fat content of DGS, approximately 11.9% (Buckner et al., 2011), increases dietary fat, and energy, however, seems to be partially protected from complete biohydrogenation. Vander Pol et al. (2009) reported that cattle fed wet DGS had greater proportions of unsaturated fatty acids reaching the duodenum compared to cattle fed similar amounts of corn oil supporting the theory that fat in DGS is protected from rumen biohydrogenation and utilized more efficiently by the animal.

The ethanol industry has developed techniques to extract the fat in the form of corn oil, which can be marketed to the biodiesel industry or other feed markets. There are 2 processes utilized for oil extraction: front-end fractionation and back-end oil extraction. Front-end fractionation involves separating the germ, endosperm, and bran fractions before fermentation while back-end extraction removes oil from thin stillage via centrifugation after fermentation has occurred (U.S. Grains Council, 2012). The thin stillage phase, which contains approximately 30% of the available oil, is the only location that can undergo centrifugation to remove corn oil, producing de-oiled (DO) condensed distillers solubles (CDS) following evaporation (U.S. Grains Council, 2012). The process of corn oil removal is widely utilized with approximately 85% of all U.S. ethanol plants producing corn distillers oil and DGS containing less than 10% fat (Musser et al., 2013; Renewable Fuels Association, 2016). Limited data are available on animal performance when this centrifugation process is utilized to remove corn oil. Therefore, 3 experiments were conducted to evaluate animal performance, carcass characteristics, and digestion in steers fed finishing diets containing DGS or CDS produced from either a traditional dry-grind or have undergone back-end oil extraction.

MATERIALS AND METHODS

All animal care and management procedures were approved by the University of Nebraska Lincoln Institution of Animal Care and Use Committee under protocol #517.

Experiment 1

A 179-d finishing experiment was conducted using 225 crossbred, calf-fed steers (initial BW = 300 ± 9.1 kg) in a randomized block design,

with a $2 \times 2 + 1$ factorial arrangement of treatments. Steers were received at the University of Nebraska's Agricultural Research and Development Center (research feedlot near Mead, NE) in the fall of 2011.

Initial processing included vaccination with a modified live viral vaccine (Bovi-Shield Gold 5, Zoetis Animal Health, Madison, NJ), *Haemophilus somnus* bacterin (Somubac, Zoetis Animal Health), and administered an injectable dewormer (Dectomax Injectable, Zoetis Animal Health). Approximately 27 d later, cattle were revaccinated with a modified live viral vaccine (Bovi-Shield Gold 5, Zoetis Animal Health), *H. somnus* bacterin (Somubac, Zoetis Animal Health), and pink-eye vaccine (Piliguard Pinkeye + 7, Merck Animal Health, Desoto, KS). Steers were implanted with Revalor-IS (80 mg of trenbolone acetate and 16 mg of estradiol; Merck Animal Health) on day 1 and reimplanted with Revalor-S (120 mg of trenbolone acetate and 24 mg of estradiol; Merck Animal Health) on day 83.

Steers were limit fed a 1:1 blend (DM basis) of alfalfa hay and wet corn gluten feed (Sweet Bran, Cargill, Blair, NE) for 5 d at 2% of BW prior to the initiation of the trial and weighed on 2 consecutive days (0 and 1) to determine initial BW (Stock et al., 1983; Watson et al., 2013). Steers were blocked by initial BW into a light or heavy block with 2 and 3 replication of each treatment, respectively. Steers were stratified by BW within each block and assigned randomly to pen using day 0 BW. Pens were assigned randomly to 1 of 5 treatments with 9 steers per pen and 5 pens per treatment.

Dietary treatments (Table 1) were arranged in a $2 \times 2 + 1$ factorial treatment design with factors including by-product type [CDS or modified distillers grains plus solubles (MDGS)] and oil concentration [DO or full fat (FF)], and a corn-based control diet (CON). Basal ingredients consisted of a 1:1 blend of dry-rolled and high-moisture corn, 7.5% sorghum silage, and 5% dry supplement (DM basis). Modified DGS were procured at the initiation of the experiment from Green Plains LLC (Central City, NE) on 2 different weeks, when the oil removal process was in operation or turned off, and stored in Ag-Bags (Ag-Bag, St. Nazianz, WI). Condensed distillers solubles were sourced from the same plant and received approximately every 3 wk throughout the experiment on alternating weeks, with or without the oil process operating in the plants. Once a week, the ethanol plant was required to shut off the centrifuges to allow for proper maintenance and cleaning. At that time, FF CDS was acquired. The DO CDS utilized in this

Table 1. Composition of diets (% of diet DM) fed to finishing steers (Exp. 1)

	Control	27% CDS		40% MDGS	
		De-oiled ¹	Full fat ¹	De-oiled ¹	Full fat ¹
Ingredient, % of DM ²					
DRC	43.75	30.25	30.25	23.75	23.75
HMC	43.75	30.25	30.25	23.75	23.75
MDGS: de-oiled	—	—	—	40	—
MDGS: normal fat	—	—	—	—	40
CDS: de-oiled	—	27	—	—	—
CDS: normal fat	—	—	27	—	—
Sorghum silage	7.5	7.5	7.5	7.5	7.5
Supplement ³					
Fine ground corn	1.03	2.59	2.59	2.59	2.59
Limestone	1.47	1.89	1.89	1.89	1.89
Urea	1.52	—	—	—	—
Potassium chloride	0.48	—	—	—	—
Salt	0.30	0.30	0.30	0.30	0.30
Tallow	0.13	0.13	0.13	0.13	0.13
Beef trace mineral ⁴	0.05	0.05	0.05	0.05	0.05
Vitamin A-D-E ⁵	0.02	0.02	0.02	0.02	0.02
Rumensin-90 ⁶	0.02	0.02	0.02	0.02	0.02
Tylan-40 ⁷	0.01	0.01	0.01	0.01	0.01
Analyzed composition, % ⁸					
CP	12.4	13.9	13.2	18.3	18.0
NDF	15.7	12.2	12.2	22.3	22.9
Fat	4.43	4.72	8.80	6.12	7.19
S	0.14	0.44	0.31	0.34	0.30

¹De-oiled CDS = 6.0% fat; full-fat CDS = 21.1% fat; de-oiled MDGS = 9.2% fat; full-fat CDS = 11.8% fat.

²DRC = dry-rolled corn; HMC = high-moisture corn; MDGS = modified distillers grains plus solubles; CDS = condensed distillers solubles; Soypass was included in the control diet at 2.83% and CDS diets at 4.46% for 38 and 60 d, respectively, to meet MP requirements.

³Supplement formulated to be fed at 5.0% of diet DM.

⁴Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.28% Mg, 0.2% I, 0.05% Co.

⁵Premix contained 30,000 IU of Vitamin A; 6,000 IU of Vitamin D; 7.5 IU of Vitamin E per gram.

⁶Premix contained 200 g/kg of monensin.

⁷Premix contained 88g/kg tylosin.

⁸Composition based on analyzed nutrients for each ingredient.

experiment contained 6.0% fat, 29.6% CP, 1.26% S, and 27.0% DM; FF CDS contained 21.1% fat, 27.0% CP, 0.78% S, and 27.5% DM; DO MDGS contained 9.2% fat, 33.7% CP, 0.65% S, 29.4% NDF, and 46% DM; and FF MDGS contained 11.8% fat, 33.0% CP, 0.56% S, 31.9% NDF, and 46.5% DM. Dietary fat consisted of 4.7, 8.8, 6.1, 7.2, and 4.4 for DO CDS, FF CDS, DO MDGS, FF MDGS, and CON, respectively. Soypass (Borregaard LignoTech, Sarpsborg, Norway) was included in CON and CDS diets for 38 and 60 d, respectively, to meet MP requirements (National Research Council, 1996). Urea was included in the control treatment at 1.52% of the diet on a DM basis. All diets contained 5% supplement that was formulated to provide 345 and 90 mg per steer daily (DM basis) of monensin (Elanco Animal Health, Greenfield, IN) and tylosin (Elanco Animal Health), respectively.

Cattle were fed once daily at approximately 0800 h. Feed bunks were managed to contain crumbs of feed remaining at feeding time. When needed, refused feed was removed from feed bunks, weighed, and dried in a forced-air oven at 60°C (model LBB2-21-1; Despatch Industries, Minneapolis, MN) for 48 h (AOAC, 1999; method 4.1.03) to determine DM for accurate DMI. Samples of each feed ingredient were collected weekly and analyzed for DM (AOAC, 1999; method 4.1.03). Weekly feed samples were composited and analyzed for OM (AOAC, 1999; method 4.1.10), CP (AOAC, 1999 method 990.03) using a combustion-type N analyzer (TruSpec N Determinator; Leco Corporation, St. Joseph, MI), sulfur (TruSpec Sulfur Add-On Module, Leco Corporation, St. Joseph, MI), and NDF (Van Soest et al., 1991) incorporating heat stable α -amylase (Ankom Technology, Macedon, NY) at 1 mL/100 mL of NDF solution during the

1 h of boiling along with the addition of 0.5 g of Na_2SO_3 to the NDF solution. The NDF procedure was conducted after samples had undergone a biphasic lipid extraction described by [Bremer et al. \(2010a\)](#). Ingredient samples are heated for 9 h with a 1:1 mixture of hexane and diethyl ether. After 9 h, diluted HCl is added, and the sample is centrifuged to separate out the lipid layer, which is pipetted into a separate tube. The procedure is repeated to ensure all lipids are extracted. Heat is then used to evaporate remaining solvent resulting in the fat for the ingredient.

Before shipping to slaughter, final live BW was measured by weighing steers by pen and applying a 4.0% pencil shrink. All animals were harvested on day 180 at a commercial abattoir (Greater Omaha, Omaha, NE) with HCW and liver abscesses recorded at that time. Following a 48-h chill, carcass 12th rib fat, LM area, and USDA marbling score were captured by cameras within the plant and recorded at time of grading. Yield grade was calculated using the USDA YG equation: $\text{YG} = 2.5 + 2.5 (\text{fat thickness, cm}) - 0.32 (\text{LM area, cm}^2) + 0.2 (\text{KPH fat, \%}) + 0.0038 (\text{HCW, kg})$; [Boggs and Merkel, 1993](#)). Calculated final BW, ADG, and G:F were calculated using HCW adjusted to a common dressing percentage of 63%.

Feeding values for the by-product treatments were calculated as the difference between the observed G:F for each by-product treatment and the control divided by the observed control G:F value. This value is then divided by the level of inclusion of by-product in the diet ([Bremer et al., 2011](#)). Dietary treatment energy values were determined utilizing pen performance data in the [Galyean \(2017\)](#) Net Energy Calculator. This calculator utilizes initial BW, final BW, DMI, ADG, and a target endpoint (assumed choice quality grade).

Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) as a randomized block design with pen as the experimental unit. The model included block and treatment as fixed effects. Initially, the 2×2 factorial was analyzed for an interaction. When an interaction was not significant, pairwise comparisons for treatments, including the control, were determined by Fisher's LSD method when the F test statistic was significant at an alpha level of $P = 0.05$. If a significant interaction was observed, then simple effects were analyzed. If a significant interaction was not observed, main effects of oil concentration and by-product type were evaluated. Two preplanned contrasts were used to evaluate the effect of oil removal when 27% CDS or 40% MDGS were fed.

Experiment 2

A 111-d metabolism experiment utilized 6 ruminally fistulated crossbred steers ($\text{BW} = 591 \pm 20$ kg) in a 5×5 Latin Square design. A $2 \times 2 + 1$ factorial arrangement of treatments was used, which are similar to Exp. 1. All diets contained a 1:1 blend of dry-rolled and high-moisture corn, which was replaced by either CDS or MDGS, 12% corn silage, and a 5% supplement ([Table 2](#)). The by-products utilized in the trial were procured from Green Plains LLC (Central City, NE). The DO CDS utilized in this experiment contained 8.7% fat, 29.9% CP, and 1.26% S; FF CDS contained 15.4% fat, 25.5% CP, and 0.78% S; DO MDGS contained 9.2% fat, 33.9% CP, 0.65% S, and 29.7% NDF; and FF MDGS contained 12.3% fat, 32.4% CP, 0.56% S, and 36.4% NDF. Dietary fat consisted of 5.2, 7.0, 5.9, 7.2, and 4.0 for DO CDS, normal CDS, DO MDGS, normal MDGS, and CON, respectively. Steers were adapted to a high grain diet by utilizing RAMP (a complete-feed starter ration consisting of Sweet Bran and a small portion of alfalfa hay; Cargill Corn Milling, Blair, NE).

Steers were housed in 2.4×1.5 m² individual concrete slatted pens, in a temperature-controlled room (25°C) with ad libitum access to feed and water. Cattle were fed once daily at 0800 h and refused feed removed from bunks prior to feeding. Dietary treatments were mixed weekly in a stationary ribbon mixer (model S-5 Mixer; H. C. Davis Sons Manufacturing Co., Inc., Bonner Springs, KS). Mixed diets were dispensed into 200-L barrels and stored in a walk in cooler at 4°C. Ingredient samples were taken during the collection period at time of mixing, composited by period and frozen at -4°C. Refused feed was collected daily before time of feeding during the collection period, composited by period, and stored frozen at -4°C. A subsample of each day feed refusals (10%) was collected and dried in a forced-air oven (Despatch Industries) for 48 h ([AOAC, 1999](#); method 4.1.03) to determine DM and adjust for DMI. At the completion of each period, ingredients and refused feed composites were freeze dried (Virtis Freezemobile 25ES, Life Scientific, Inc., St. Louis, MO) and ground through a 1-mm screen of a Willey Mill (No. 4, Thomas Scientific, Swedesboro, NJ).

Period duration was 21 d, which consisted of a 16-d adaptation phase and 5-d collection period of fecal samples, pH data, and total gas production. Titanium dioxide, an indigestible marker, was dosed intraruminally twice daily at 0800 and 1600 h to provide a total of 20 g/d. Beginning on day 10

Table 2. Composition of diets (% of diet DM) fed to finishing steers (Exp. 2)

		27% CDS		40% MDGS	
	Control	De-oiled ¹	Full fat ¹	De-oiled ¹	Full fat ¹
Ingredient, % of DM ²					
DRC	41.5	28	28	21.5	21.5
HMC	41.5	28	28	21.5	21.5
MDGS: de-oiled	—	—	—	40	—
MDGS: normal fat	—	—	—	—	40
CDS: de-oiled	—	27	—	—	—
CDS: normal fat	—	—	27	—	—
Corn silage	12	12	12	12	12
Supplement ³					
Fine ground corn	1.03	2.59	2.59	2.59	2.59
Limestone	1.47	1.89	1.89	1.89	1.89
Salt	0.30	0.30	0.30	0.30	0.30
Tallow	0.13	0.13	0.13	0.13	0.13
Beef trace mineral ⁴	0.05	0.05	0.05	0.05	0.05
Vitamin A-D-E ⁵	0.02	0.02	0.02	0.02	0.02
Potassium chloride	0.48	—	—	—	—
Urea	1.52	—	—	—	—
Rumensin-90 ⁶	0.02	0.02	0.02	0.02	0.02
Tylan-40 ⁷	0.01	0.01	0.01	0.01	0.01
Analyzed composition, % ⁸					
CP	12.4	14.8	13.8	19.0	18.5
NDF	13.2	10.2	11.9	19.9	22.6
Fat	4.01	5.17	6.99	5.93	7.16
S	0.14	0.30	0.25	0.28	0.27

¹De-oiled CDS = 8.7% fat; normal CDS = 15.4% fat; de-oiled MDGS = 9.2% fat; normal CDS = 12.3% fat.

²DRC = dry-rolled corn; HMC = high-moisture corn; MDGS = modified distillers grains plus solubles; CDS = condensed distillers solubles.

³Supplement formulated to be fed at 5.0% of diet DM.

⁴Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.28% Mg, 0.2% I, 0.05% Co.

⁵Premix contained 30,000 IU of Vitamin A; 6,000 IU of Vitamin D; 7.5 IU of Vitamin E per gram.

⁶Premix contained 200 g/kg of monensin.

⁷Premix contained 88g/kg tylosin.

⁸Composition based on analyzed nutrients for each ingredient.

of each period, the titanium dioxide was administered to provide an estimate of fecal output. On days 17 to 21, fecal grab samples were collected 3 times per day at 0800, 1200, and 1600 h, and immediately frozen at -4°C . At the end of each period, fecal samples were composited (wet basis within day), freeze dried (Life Scientific, Inc.), and ground through a 1-mm screen of a Wiley Mill (number 4; Thomas Scientific). Ground daily samples were composited by steer within collection period on a dry weight basis.

Feed ingredients and fecal sample analysis consisted of DM, OM, CP, NDF, and fat according to the procedures outlined for Exp. 1. Dietary nutrient composition and fecal composition were used to calculate total tract digestibility of DM, OM, and NDF with the following equation (Cochran and Galylean, 1994): $[(\text{kilogram of nutrient in feed} - \text{kilogram of nutrient refused} - \text{kilogram of nutrient in feces}) / (\text{kilogram of nutrient fed} - \text{kilogram$

of nutrient refused)] $\times 100$. Fecal samples were analyzed for titanium dioxide using the procedure described by Myers et al. (2004). Fecal DM output was calculated from the TiO_2 concentration using the following equation (Cochran and Galylean, 1994): gram marker dosed per day/concentration of marker in feces. Gross energy content (calories per gram) of the feed and fecal samples were analyzed using a bomb calorimeter (Parr 1281; Parr Instrument Company, Moline, IL). Digestible energy was calculated by subtracting the total GE intake from fecal energy (National Research Council, 1996).

Ruminal pH was measured continuously from days 17 to 21 with submersible wireless pH probes (Dascor, Inc., Escondido, CA). Cylindrical weights were attached to the probes to ensure placement in the ventral sac of the rumen. All pH probes were calibrated prior to rumen insertion and after removal by submersing them in pH 7 and 4 standard

solutions. Ruminal pH measurements were adjusted by using both calibrations. Ruminal pH measurements were recorded every minute (1,440 measurements per day) and downloaded on day 21 of each collection period. Measurements for pH include average ruminal pH, minimum and maximum pH, and magnitude. Ruminal pH variance, time below 5.6, and area below 5.6 were calculated as described by Cooper et al. (1999).

Intake, digestibility, and energy data were analyzed as a Latin Square design using the MIXED procedure of SAS (SAS Inst., Inc.). Included in the model were the fixed effects of treatment and period, whereas steer was treated as a random effect for all analyses. Steer within period was the experimental unit for all analyses. The 2×2 factorial was analyzed for an interaction. When an interaction was not reported, pairwise comparisons for treatments, including the control, were determined by Fisher's LSD method. The simple effects were analyzed if a significant interaction was observed. If a significant interaction was not observed, then the main effects of oil concentration and by-product type were evaluated. Two preplanned contrasts were utilized to evaluate the effect of oil removal when 27% CDS or 40% MDGS were fed. Ruminal pH data were analyzed as a repeated measure using the GLIMMIX procedure of SAS. Day was analyzed as a repeated measure with period, day, and treatment included in the model statement. A Kenward–Rogers denominator degrees of freedom adjustment was used with steer treated as a random effect. Treatment differences were considered significant at $P \leq 0.10$.

Experiment 3

A 147-d finishing experiment was conducted using 336 crossbred, yearling steers (initial BW = 352 ± 19 kg) in a randomized block design, with a $2 \times 3 + 1$ factorial arrangement of treatments. Steers were received at the University of Nebraska's Agricultural Research and Development Center in the fall of 2011, backgrounded by grazing cornstalk residue over the winter months, and grazed smooth brome pastures until initiation of the trial in May of 2012. Initial processing and revaccination was similar to Exp. 1. Steers were implanted on day 1 with Revalor-XS (4 mg of estradiol and 20 mg of trenbolone acetate; Merck Animal Health).

Steers were limit fed a 1:1 blend of alfalfa hay and wet corn gluten feed (Sweet Bran, Cargill) for 5 d at 2% of BW prior to the initiation of the trial (Watson et al., 2013). Steers were weighed on 2

consecutive days (0 and 1) and averaged to determine initial BW (Stock et al., 1983). Steers were blocked by BW into a light, medium, or heavy weight block with 2, 3, and 1 replication per block, respectively. Steers were stratified by BW within each block and assigned randomly to pen based on day 0 BW. Pens were assigned randomly to 1 of 7 treatments with 6 pens per treatment and 8 steers per pen.

A $2 \times 3 + 1$ factorial arrangement of treatments was used, with factors being oil concentration (DO or FF) by level of wet distillers grains plus solubles (WDGS) in the diet (35%, 50%, 65%) plus a corn-based control (Table 3). Wet DGS were sourced from KAAPA Ethanol, LLC (Minden, NE) and received approximately every 3 wk throughout the experiment. Feed ingredients were analyzed for DM, CP, NDF, S, and fat according to the procedures outlined in Exp. 1. The DO WDGS contained 7.9% fat, 30.5% CP, 48.0% NDF, and 0.76% S, and FF WDGS contained 12.4% fat, 29.3% CP, 51.5% NDF, and 0.73% S. Dietary fat concentrations are included in Table 3. Urea was included in the control treatment at 1.58% of the diet on a DM basis. All diets contained a 1:1 blend of dry-rolled and high-moisture corn, 12% corn silage, and 5% supplement, which was formulated to contain 383 and 90 mg per steer daily of monensin and tylosin, respectively (Elanco Animal Health).

All animals were harvested on day 148 at a commercial abattoir (Greater Omaha, Omaha, NE) with hot carcass weights (HCW) and liver scores recorded at slaughter. Carcass 12th rib fat, LM area, and USDA marbling score were recorded after a 48-h carcass chill. Yield grade was calculated using the USDA YG equation [$YG = 2.5 + 2.5$ (fat thickness, in) $- 0.32$ (LM area, in²) $+ 0.2$ (KPH fat, %) $+ 0.0038$ (HCW, lb)]. Final BW, ADG, and G:F were calculated using HCW adjusted to a common dressing percentage of 63%. By-product feeding values and energy values were calculated similarly to Exp. 1.

Data were analyzed using the GLIMMIX procedure of SAS as a randomized block design. Pen was the experimental unit, and block was treated as a fixed effect. The 2×3 factorial treatment design was analyzed for a fat (DO and FF) by inclusion (0%, 35%, 50%, 65%) interaction. Using the control as the common intercept, orthogonal contrasts were developed. PROC IML was used to determine appropriate coefficients due to unequal spacing of WDGS inclusion level. Differences were considered significant at a $P \leq 0.05$.

Table 3. Composition of diets (% of diet DM) fed to finishing steers (Exp. 3)

	Control	35% WDGS		50% WDGS		65% WDGS	
		De-oiled	Full fat	De-oiled	Full fat	De-oiled	Full fat
Ingredient, % of DM ¹							
DRC	41.5	24	24	16.5	16.5	9	9
HMC	41.5	24	24	16.5	16.5	9	9
WDGS: de-oiled	—	35	—	50	—	65	—
WDGS: normal fat	—	—	35	—	50	—	65
Corn silage	12	12	12	12	12	12	12
Supplement ²							
Fine ground corn	1.46	2.54	2.54	2.54	2.54	2.54	2.54
Limestone	1.45	1.95	1.95	1.95	1.95	1.95	1.95
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Tallow	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Urea	1.58	—	—	—	—	—	—
Beef trace mineral ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Vitamin A-D-E ⁴	0.02	0.2	0.2	0.2	0.2	0.2	0.2
Rumensin-90 ⁵	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Tylan-40 ⁶	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Analyzed composition, % ⁷							
CP	12.8	16.2	15.8	19.4	18.8	22.6	21.9
NDF	13.5	26.6	27.8	32.3	34.0	38.0	40.2
Fat	4.47	5.49	7.06	5.98	8.22	6.39	9.31
S	0.09	0.32	0.31	0.42	0.41	0.52	0.51

¹DRC = dry-rolled corn; HMC = high-moisture corn; WDGS = wet distillers grains plus solubles.

²Supplement formulated to be fed at 5.0% of diet DM.

³Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.28% Mg, 0.2% I, 0.05% Co.

⁴Premix contained 30,000 IU of Vitamin A; 6,000 IU of Vitamin D; 7.5 IU of Vitamin E per gram.

⁵Premix contained 200 g/kg of monensin.

⁶Premix contained 88g/kg tylosin.

⁷Composition based on analyzed nutrients for each ingredient.

RESULTS AND DISCUSSION

Experiment 1

There were no oil concentration by by-product type interactions ($P \geq 0.34$; Table 4) observed for animal performance, energy values, or carcass characteristics. No significant differences ($P \geq 0.20$) were observed for the main effects of oil concentration for animal performance, energy values, or carcass characteristics. These results disprove the initial hypothesis that removing a portion of corn oil, via centrifugation, from the thin stillage phase would result in negative effects on cattle performance. The main effect of by-product type was significant for final BW, DMI, and ADG ($P \leq 0.04$) with cattle fed MDGS having greater final BW, DMI, and ADG compared with cattle fed CDS. However, G:F was not different between cattle fed MDGS or CDS ($P = 0.91$) because steers fed CDS consumed 0.6 kg less feed with comparable ADG to steers fed MDGS. No significant differences were observed for the main effect of by-product type on calculated

NE_m or NE_g of diets ($P \geq 0.27$). Cattle fed MDGS had greater HCW and calculated YG compared to cattle fed CDS ($P \leq 0.04$).

Effect of Fat Concentration with CDS

Dietary fat for DO and FF CDS was 4.72% and 8.80%, respectively. Even though dietary fat for FF CDS was twice that of DO CDS, DMI was 8.8 kg/d for both treatments. Utilizing a protected *F* test, cattle fed CDS, regardless of oil concentration, had significantly ($P = 0.01$) lower DMI than cattle fed MDGS or CON. A reduction in DMI is typically the most consistent response observed with increased fat supplementation (Hall and Eastridge, 2014), which was not observed in the current experiment. When supplemental fat was supplied by tallow or yellow grease, DMI either decreased or remained unchanged. Hatch et al. (1972) fed 3%, 6%, and 9% supplemental animal fat in finishing diets and observed a reduction in DMI as animal fat increased in the diet. Zinn (1994) reported a quadratic reduction in DMI when 4%,

Table 4. Effect of feeding de-oiled and full-fat CDS and MDGS on finishing performance (Exp. 1)

	CON ¹	27% CDS		40% MDGS		SEM	P value					
		De-oiled	Normal	De-oiled	Normal		F test ²	Int ³	Oil ⁴	Type ⁵	CDS ⁶	MDGS ⁷
Performance												
Initial BW, kg	300	300	301	300	300	1	0.39	0.85	0.89	0.91	0.17	0.68
Final BW ⁸ , kg	567 ^a	588 ^{b,c}	580 ^{a,b}	595 ^{b,c}	599 ^c	14	0.01	0.39	0.77	0.04	0.43	0.61
DMI, kg/d	9.5 ^a	8.8 ^b	8.8 ^b	9.3 ^a	9.5 ^a	0.4	0.01	0.70	0.74	<0.01	0.97	0.58
ADG ⁹ , kg	1.49 ^a	1.60 ^{b,c}	1.56 ^{a,b}	1.64 ^{b,c}	1.67 ^c	0.08	0.02	0.34	0.73	0.04	0.36	0.60
G:F	0.157 ^a	0.182 ^b	0.177 ^b	0.176 ^b	0.175 ^b	0.004	<0.01	0.39	0.53	0.91	0.29	0.80
Feeding value ¹⁰	—	159%	147%	130%	129%							
Energy values ¹¹												
NE _m , Mcal/kg	1.81 ^b	1.98 ^a	1.94 ^a	1.93 ^a	1.92 ^a	0.03	0.01	0.51	0.47	0.27	0.34	0.96
NE _g , Mcal/kg	1.18 ^b	1.32 ^a	1.29 ^a	1.28 ^a	1.28 ^a	0.03	0.02	0.53	0.59	0.30	0.43	0.96
Carcass characteristics												
HCW, kg	357 ^a	370 ^{b,c}	366 ^{a,b}	375 ^{b,c}	377 ^c	9	0.01	0.39	0.79	0.04	0.43	0.61
LM area, cm ²	81.0	85.1	82.7	82.6	81.6	0.23	0.38	0.46	0.20	0.36	0.25	0.66
12th rib fat, cm	1.27	1.27	1.19	1.35	1.42	0.03	0.28	0.42	0.95	0.06	0.47	0.47
Calculated YG	3.21	3.11	3.15	3.37	3.49	0.11	0.13	0.73	0.52	0.03	0.81	0.44
Marbling score ¹²	570	579	575	594	599	14	0.50	0.84	0.96	0.15	0.85	0.77

^{a,b,c}Within a row, means without a common superscript letter differ ($P \leq 0.05$).

¹CON = corn-based control.

²F test = overall F test representing variation due to treatment.

³Int = Interaction P value for by-product type and oil concentration.

⁴Oil = main effect of oil concentration.

⁵Type = main effect of by-product type.

⁶CDS = pairwise, contrast of de-oiled vs. normal CDS.

⁷MDGS = pairwise, contrast of de-oiled vs. normal MDGS.

⁸Calculated from hot carcass weight, adjusted to a common dressing percentage of 63.0%.

⁹Calculated using carcass adjusted final BW.

¹⁰Feeding value calculation = difference between the by-product treatment G:F and control G:F divided by control G:F and divided by the treatment inclusion in the diet.

¹¹Values calculated by pen using the 1996 NRC equations.

¹²Marbling score: 500 = Small00.

8%, and 12% supplemental tallow was added to the diet. Surprisingly, [Huffman et al. \(1992\)](#) observed a decrease in DMI with as low as 2% supplemental tallow. [Zinn and Shen \(1996\)](#) fed 0% or 5% added yellow grease in finishing diets and observed a reduction in DMI. However, [Brandt and Anderson \(1990\)](#) reported no difference in DMI when 3.5% tallow or 3.5% yellow grease were fed in finishing diets. Similarly, [Zinn \(1989a\)](#) reported no difference in DMI when 4% or 8% supplemental yellow grease was fed. When fat was supplied by CDS, DMI decreased or was not changed. When CDS was included in diets at 27% or greater, DMI decreased ([Titlow et al., 2013](#); [Pesta et al. 2015](#)), whereas DMI was unchanged at lower inclusions ([Trenkle and Pingel, 2004](#)). However, [Trenkle](#)

(2003) observed a reduction in DMI when 8% CDS was fed in finishing diets.

There were no differences ($P \geq 0.29$) due to oil concentration for the pairwise comparison of CDS observed for ADG, G:F, NE_m, or NE_g. Utilizing a protected F test, cattle fed CDS had greater ADG and improved G:F compared with CON ($P \leq 0.02$), which is in agreement with previous research ([Titlow et al., 2013](#); [Pesta et al., 2015](#)). Regardless of oil concentration, performance calculated dietary NE_m and NE_g were greater ($P \leq 0.02$) for cattle fed CDS than CON. The calculated dietary NE_m was 1.98 and 1.94 Mcal/kg for DO and FF CDS, respectively, with CON calculated at 1.81 Mcal/kg. The calculated dietary NE_g was 1.32 and 1.29 Mcal/kg for DO and FF CDS, respectively, whereas

CON was 1.18 Mcal/kg. This resulted in 12% and 9% more energy being provided by DO and FF CDS diets, respectively, compared with the control. [Pesta et al. \(2015\)](#) observed a quadratic increase in net energy values as CDS inclusion increased up to 27% in the diet with a similar average NE_m and NE_g of 2.04 and 1.38 Mcal/kg for CDS, respectively. Calculated feeding values were 159% and 147% of dry-rolled corn for DO and FF CDS, respectively, which is similar to 142% observed by [Pesta et al. \(2015\)](#) for CDS fed at 27% of the diet DM. Even with the centrifugation of oil from the CDS stream, these data would suggest that cattle perform and receive the same amount of energy as CDS containing the full amount of fat.

Effect of Fat Concentration with MDGS

No difference was observed for DMI between DO and FF MDGS ($P \geq 0.58$) when dietary fat was 6.12% and 7.19%, respectively. A meta-analysis performed by [Bremer et al. \(2011\)](#) observed that DMI increased when traditional FF DGS increased in the diet up to 30%. The increase in DMI was attributed to the high NDF and low starch concentration of distillers grains. There were no differences ($P \geq 0.60$) due to oil concentration of MDGS for ADG, G:F, NE_m , and NE_g . Cattle fed MDGS had greater ADG and improved G:F compared with CON ($P \leq 0.02$), which is in agreement with previous research ([Klopfenstein et al., 2008](#); [Corrigan et al., 2009](#); [Bremer et al., 2011](#)). Regardless of oil concentration, performance calculated dietary NE_m and NE_g were greater ($P \leq 0.02$) for cattle fed MDGS than CON. The calculated dietary NE_m was 1.93 and 1.92 Mcal/kg for DO and FF MDGS, respectively, with CON calculated at 1.81 Mcal/kg. The calculated dietary NE_g was 1.28 Mcal/kg for both DO and FF MDGS, whereas CON was 1.18 Mcal/kg resulting in 8.5% more NE_g being provided by the MDGS diets than the CON diet. These findings are similar to those reported by [Vander Pol et al. \(2009\)](#) who observed 2.5% and 6.8% increase in dietary NE_g when 20% and 40% WDGS were fed in dry-rolled corn:high-moisture corn (DRC:HMC) blend diets. [Ham et al. \(1994\)](#) fed 40% inclusion of WDGS (DM basis) in a DRC-based diet and reported a 17% increase in dietary NE_g over the control. Results reported by [Larson et al. \(1993\)](#) stated that feeding inclusions of 5.2%, 12.6%, and 40% WDGS (DM basis) would result in a 5.8%, 10.7%, and 22% improvement in diet NE_g . However, [Hales et al. \(2012\)](#) determined the dietary NE_g of feeding 30% inclusion (DM basis) of WDGS in a DRC diet by

utilizing respiration calorimetry and reported 1.22 and 1.23 Mcal/kg for 0% WDGS and 30% WDGS diets, respectively. The feeding values for MDGS were 130% of corn for both DO and FF MDGS at 40% inclusion. [Bremer et al. \(2011\)](#) conducted a meta-analysis and reported the feeding value of MDGS to be 117% when fed at 40% inclusion in a corn-based finishing diet.

Carcass Characteristics

No differences in carcass characteristics were observed ($P \geq 0.25$) when utilizing the preplanned, pairwise comparison between DO and FF CDS or MDGS. When comparing all treatments, cattle fed DO CDS, DO MDGS, and FF MDGS had greater ($P < 0.01$) HCW compared with CON. No differences ($P \geq 0.13$) were observed for LM area, 12th rib fat thickness, calculated YG, or marbling score across all treatments.

Experiment 2

No interactions were observed for DMI or total tract DM digestibility ($P \geq 0.14$; [Table 5](#)) between by-product type and oil concentration. No significant differences were observed for the main effect of oil concentration on DM intake or DM digestibility ($P = 0.98$). No significant difference was observed for the main effect of by-product type on DM digestibility ($P = 0.34$); however, steers fed MDGS consumed more feed than steers fed CDS ($P = 0.02$). When utilizing the preplanned contrasts, DMI and total tract DM digestibility was not significantly different between DO CDS and FF CDS ($P \geq 0.17$) or DO MDGS and FF MDGS ($P \geq 0.26$). However, an effect of treatment was observed on DMI ($P = 0.05$) with cattle fed DO MDGS having the greatest DMI with cattle fed DO CDS having the least. [Pesta et al. \(2012\)](#) and [Bremer et al. \(2010b\)](#) observed that diets containing 7.4% and 8.6% dietary fat provided by CDS, respectively, had similar DMI and total tract DM digestibility compared to 4.1% and 3.7% dietary fat from a corn-based control diet, respectively. Diets containing WDGS have been reported to have either similar ([Vander Pol et al., 2009](#); [Bremer et al., 2010b](#); [Hales et al., 2012](#)) or greater ([Corrigan et al., 2009](#)) DMI and a reduction in total tract DM digestibility ([Corrigan et al., 2009](#); [Bremer et al., 2010b](#)) compared with corn-based control diets.

No interactions ($P \geq 0.21$) were observed for OM intake (OMI) or OM digestibility (OMD). No significant differences were observed for the main

Table 5. Effects of de-oiled and full-fat CDS and MDGS on intake and total tract digestibility of DM, OM, fat, and NDF (Exp. 2)

Item	CON ¹	27% CDS		40% MDGS		SEM	P value					
		De-oiled	Full fat	De-oiled	Full fat		F test ²	Int ³	Oil ⁴	Type ⁵	CDS ⁶	MDGS ⁷
DM												
Intake, kg/d	10.1 ^{a,b}	9.0 ^c	9.5 ^{b,c}	11.0 ^a	10.3 ^{a,b}	1.3	0.05	0.33	0.98	0.02	0.34	0.29
Total tract digestibility, %	81.6	81.4	83.6	82.1	80.0	1.91	0.27	0.14	0.98	0.34	0.17	0.26
OM												
Intake, kg/d	9.7 ^{a,b}	8.5 ^c	9.0 ^{b,c}	10.5 ^a	9.9 ^a	1.2	0.03	0.33	0.95	0.01	0.29	0.32
Total tract digestibility, %	82.9 ^{b,c}	84.6 ^{a,b}	86.0 ^a	83.6 ^{a,b,c}	81.9 ^c	1.81	0.08	0.21	0.90	0.07	0.30	0.30
NDF												
Intake, kg/d	1.32 ^c	0.86 ^d	0.94 ^d	2.10 ^b	2.33 ^a	0.24	<0.01	0.40	0.10	<0.01	0.43	0.06
Total tract digestibility, %	58.0	53.6	61.0	67.0	67.0	5.51	0.12	0.38	0.39	0.05	0.17	0.99
Fat												
Intake, kg/d	0.41 ^c	0.46 ^c	0.66 ^b	0.66 ^b	0.74 ^a	0.08	<0.01	0.07	<0.01	<0.01	<0.01	0.05
Total tract digestibility, %	87.3 ^c	89.6 ^{b,c}	93.1 ^a	91.2 ^{a,b}	90.6 ^b	1.3	0.01	0.03	0.11	0.54	0.02	0.68
Energy												
Intake, Mcal/d	45.47 ^b	44.32 ^b	47.65 ^b	54.39 ^a	52.0 ^a	2.90	0.02	0.32	0.75	0.01	0.20	0.43
Excreted, Mcal/d	8.79 ^{a,b}	7.52 ^{b,c}	7.02 ^c	9.48 ^a	9.77 ^a	0.84	0.01	0.44	0.93	<0.01	0.48	0.72
DE, Mcal/d	36.65 ^b	36.79 ^b	40.64 ^{a,b}	45.05 ^a	42.24 ^a	2.82	0.04	0.19	0.75	0.05	0.12	0.32
DE, Mcal/kg	3.63 ^c	4.06 ^b	4.24 ^a	4.09 ^b	4.07 ^b	0.09	<0.01	0.15	0.25	0.31	0.02	0.81

^{a,b,c}Within a row, means without a common superscript letter differ ($P \leq 0.10$).

¹CON = corn-based control.

²*F* test = overall *F* test representing variation due to treatment.

³Int = interaction *P* value for by-product type and oil concentration.

⁴Oil = main effect of oil concentration.

⁵Type = main effect of by-product type.

⁶CDS = pairwise, contrast of de-oiled vs. full-fat CDS.

⁷MDGS = pairwise, contrast of de-oiled vs. full-fat MDGS.

effect of oil concentration on OMI or OMD ($P \geq 0.90$). Steers that were fed CDS had lower ($P = 0.01$) OMI and greater OMD ($P = 0.07$) than steers fed MDGS. There were no differences observed for OMI or OMD when analyzing the preplanned contrasts between DO and FF CDS ($P \geq 0.29$) and DO and FF MDGS ($P \geq 0.30$). However, an effect of treatment was observed for OMI ($P = 0.03$) and OMD ($P = 0.08$). Steers fed MDGS, regardless of oil concentration, had the greatest OMI, whereas FF CDS and CON were intermediate, and DO CDS had the lowest OMI. Cattle on the FF CDS treatment had the greatest OMD compared with FF MDGS, which had the lowest. Similarly, Ham et al. (1994) reported that cattle fed thin stillage had greater OMD compared with DRC, whereas Pesta et al. (2012) reported no difference. Ham et al. (1994) and Vander Pol et al. (2009) reported WDGS to have similar OMD to a corn-based diet.

No interactions ($P \geq 0.38$) were observed for NDF intake or NDF digestibility. The main effect

of oil removal was significant for NDF intake ($P = 0.10$) with steers fed a DO product had a reduction in NDF intake. However, NDF digestibility was not impacted by oil removal ($P = 0.39$). The main effect of by-product type was significant for NDF intake ($P < 0.01$) and NDF digestibility ($P = 0.05$) with cattle fed MDGS having greater NDF intakes and NDF digestibility compared with CDS. No differences were observed for the preplanned contrast of DO and FF CDS for NDF intake and NDF digestibility ($P \geq 0.17$). Steers fed FF MDGS had greater NDF intakes compared with steers fed DO MDGS ($P = 0.06$) due to a greater dietary concentration of NDF. Utilizing the protected *F* test, a treatment effect was observed for NDF intake ($P < 0.01$). Intake of NDF was dramatically greater for MDGS than CDS or CON because of the greater NDF concentration of MDGS. No effect of treatment ($P = 0.12$) was observed for total tract NDF digestibility. Similarly, Pesta et al. (2012) reported no difference

($P = 0.71$) in NDF digestibility when steers were fed 27% inclusion of CDS compared with a corn-based control. However, [Ham et al. \(1994\)](#) reported thin stillage and wet distillers grains to be significantly greater in NDF digestibility ($P < 0.10$) than a corn-based diet. Previous research has shown that cattle fed DGS have similar NDF digestibility compared with corn-based control diets ([Corrigan et al., 2009](#); [Vander Pol et al., 2009](#); [Bremer et al., 2010a,b](#); [Pesta et al., 2012](#)). More typical sources of supplemental fat, such as yellow grease or blended animal-vegetable fats, will decrease NDF and ADF digestibility by physically coating fiber particles or inhibiting cellulolytic activity ([Zinn, 1989b](#); [Zinn et al., 2000](#)). It appears that lipids from dry milling by-products do not decrease fiber digestion like typical fat sources.

An oil concentration by by-product type interaction was observed for fat intake ($P = 0.07$) and total tract fat digestibility ($P = 0.03$). Fat intake was the greatest for FF MDGS (0.74 kg/d), intermediate for FF CDS (0.66 kg/d) and DO MDGS (0.66 kg/d), and the least for DO CDS (0.46 kg/d). Total tract fat digestibility was greater for FF CDS, intermediate for DO and FF MDGS, and the least for DO CDS. When comparing the preplanned contrasts of DO and FF, oil concentration affected total tract fat digestibility for CDS ($P = 0.02$), but not for MDGS ($P = 0.68$). Cattle fed FF CDS had a total tract fat digestibility of 93.1% compared with 89.6% for DO CDS.

No interactions were observed for GE or DE parameters ($P \geq 0.15$; [Table 5](#)). There was no difference for the main effect of oil concentration ($P = 0.25$) on GE intake. However, cattle that were fed MDGS consumed a greater amount of GE compared with cattle fed CDS ($P = 0.01$). Gross energy intakes were also not different between DO and FF CDS ($P = 0.20$) or between DO and FF MDGS ($P = 0.43$). When comparing the 4 by-product treatments with the control, cattle fed MDGS, regardless of oil concentration, consumed more Mcal per day than cattle fed CDS or CON ($P = 0.02$). There was no difference for the main effect of oil concentration ($P = 0.93$) on fecal energy loss. However, cattle that were fed MDGS excreted a greater amount of GE compared with cattle fed CDS ($P = 0.01$), which could be attributed to the differences in GE intake. There were no differences for the amount of fecal energy loss between DO and FF CDS ($P = 0.48$) or between DO and FF MDGS ($P = 0.72$). When comparing all 5 treatments, cattle fed MDGS, regardless of oil concentration, excreted more megacalories per day, CON

being intermediate, and cattle fed the CDS treatments excreted the least ($P = 0.01$). There was no difference for the main effect of oil concentration for megacalorie of DE per day ($P = 0.75$). However, steers on the MDGS treatment had a greater concentration of DE than steers fed CDS ($P = 0.05$). When comparing all 5 treatments, DE was greater for cattle fed MDGS, regardless of oil concentration, intermediate for FF CDS, and least for DO CDS and CON ($P = 0.04$). When DE was adjusted for DMI (megacalorie per kilogram), there were no main effect differences for oil concentration ($P = 0.25$) or by-product type ($P = 0.31$). However, when comparing within oil concentration, DE measured in megacalorie per kilogram was greater for cattle fed FF CDS compared with cattle fed DO CDS ($P = 0.02$). When comparing the 5 treatments, DE was the greatest for steers fed FF CDS, intermediate for DO CDS, DO MDGS, and FF MDGS, and least for steers fed CON ($P < 0.01$). [Hales et al. \(2012\)](#) fed cattle DRC or a steam-flaked corn-based diet with 0% or 30% WDGS. The authors observed that cattle fed 30% WDGS consumed more energy ($P < 0.01$) than 0% WDGS; however DE, adjusted for DMI, was not impacted by WDGS inclusion ($P = 0.32$). In a separate trial, [Hales et al. \(2015\)](#) fed DRC or a 2:1 blend of HMC and DRC with either 25% or 45% WDGS. The authors reported that when WDGS inclusion increased from 25% to 45% in the blended HMC and DRC diet, DE, as a percentage of GE intake, increased, whereas no difference was observed when WDGS inclusion increased in the DRC diet.

No interactions were observed for all ruminal pH parameters ($P \geq 0.20$; [Table 6](#)). The main effect of oil concentration was significant for average ruminal pH ($P = 0.06$) with steers fed a DO by-product having a lower average ruminal pH. By-product type impacted average ruminal pH ($P < 0.01$) with steers fed MDGS having a greater average ruminal pH than steers fed CDS. When analyzing the preplanned contrasts of DO and FF, there was no difference in average ruminal pH for CDS ($P = 0.74$); however, steers fed DO MDGS had a reduction in average ruminal pH compared with FF MDGS ($P = 0.06$). When comparing all 5 treatments, average ruminal pH was greatest for cattle fed FF MDGS and lowest for CON and DO CDS ($P < 0.01$). This is consistent with the findings of [Pesta et al. \(2015\)](#) who found average ruminal pH to increase in steers fed WDGS relative to CDS or CON diets. However, previous research would suggest that there is not a difference in average ruminal pH between WDGS

Table 6. Effects of de-oiled and full-fat CDS and MDGS on ruminal pH (Exp. 2)

Item	CON ¹	27% CDS		40% MDGS		SEM	<i>P</i> value					
		De-oiled	Normal	De-oiled	Normal		<i>F</i> test ²	Int ³	Oil ⁴	Type ⁵	CDS ⁶	MDGS ⁷
Average pH	5.36 ^a	5.38 ^a	5.41 ^{a,b}	5.54 ^b	5.72 ^c	0.08	<0.01	0.29	0.06	<0.01	0.74	0.06
Maximum pH	6.03	6.17	6.04	6.25	6.31	0.11	0.28	0.66	0.76	0.18	0.41	0.70
Minimum pH	4.87	4.92	5.01	5.07	5.07	0.08	0.19	0.62	0.39	0.07	0.35	0.98
pH magnitude	1.08	1.23	1.09	1.14	1.32	0.15	0.76	0.20	0.94	0.50	0.50	0.42
pH variance ⁸	0.079	0.092	0.081	0.080	0.111	0.021	0.78	0.33	0.74	0.99	0.72	0.30
Time < 5.6, min/d ⁹	958 ^a	923 ^a	902 ^a	652 ^b	494 ^b	100	<0.01	0.55	0.33	<0.01	0.87	0.22
Area < 5.6, min/d ¹⁰	365 ^{a,c}	356 ^{a,c}	403 ^a	238 ^{b,c}	141 ^b	71	0.02	0.29	0.59	<0.01	0.58	0.23
Time < 5.3, min/d ¹¹	679 ^a	575 ^{a,c}	709 ^a	368 ^{b,c}	252 ^b	127	0.03	0.36	0.94	0.01	0.40	0.46
Area < 5.3, min/d ¹²	136 ^{a,c}	129 ^{a,c}	162 ^a	86 ^{b,c}	41 ^b	41	0.10	0.31	0.77	0.03	0.48	0.33

^{a,b,c}Means with different superscripts differ ($P < 0.10$).

¹CON = corn-based control.

²*F* test = overall *F* test representing variation due to treatment.

³Int = interaction *P* value for by-product type and oil concentration.

⁴Oil = main effect of oil concentration.

⁵Type = main effect of by-product type.

⁶CDS = pairwise, contrast of de-oiled vs. normal CDS.

⁷MDGS = pairwise, contrast of de-oiled vs. normal MDGS.

⁸Variance of daily ruminal pH.

⁹Time < 5.6 = minutes that ruminal pH was below 5.6.

¹⁰Area < 5.6 = ruminal pH units below 5.6 by minute.

¹¹Time < 5.3 = minutes that ruminal pH was below 5.3.

¹²Area < 5.3 = ruminal pH units below 5.3 by minute.

and a corn-based finishing diet (Ham et al, 1994; Corrigan et al, 2009; Vander Pol et al., 2009; Bremer et al., 2010a,b).

The main effect of oil concentration was not significant for the remaining ruminal pH parameters ($P \geq 0.33$); however, the effect of by-product type was significant for minimum, time and area below 5.6, and time and area below 5.3 ($P \leq 0.03$). Steers fed MDGS had a greater minimum ruminal pH and spent less time and area under a ruminal pH of 5.6 and 5.3 compared with steers fed CDS, which is indicative of a reduction in acidosis because of the greater NDF content in the MDGS diets. When analyzing the preplanned contrast for DO and FF, there were no differences for the remaining ruminal pH parameters for CDS or MDGS ($P \geq 0.22$). When comparing all 5 treatments, no differences were observed for the minimum pH, maximum pH, pH magnitude, or variance ($P > 0.19$). However, steers fed CDS or CON spent more time and area with a ruminal pH below 5.6 than steers fed MDGS ($P \leq 0.02$). Likewise, steers fed CDS or CON spent more time and area with a pH below 5.3 than steers fed MDGS ($P < 0.10$).

Experiment 3

No linear or quadratic interactions were observed for initial BW, final BW, intake as percentage of BW, ADG, G:F, NE_m, or NE_g ($P \geq 0.23$; Table 7) for inclusion of WDGS (35%, 50%, or 65%) and oil concentration (DO or FF). There was a linear interaction ($P < 0.01$) for DMI producing different slopes for DO and FF WDGS. As the inclusion of DO WDGS increased in the diet from 0% to 50%, DMI remained relatively constant from 11.4 to 11.6 kg/d, whereas when dietary inclusion increased from 50% to 65%, DMI decreased from 11.6 to 10.9 kg/d. However, as the inclusion of FF WDGS increased from 0% to 50%, DMI decreased from 11.4 to 10.9 kg/d, and as the dietary inclusion of WDGS increased from 50% to 65%, DMI decreased further from 10.9 to 10.4 kg/d. This agrees with previous research suggesting that as inclusion of WDGS increases above 30% of diet DM, cattle tend to have decreased DMI relative to lower inclusions (Larson et al., 1993; Klopfenstein et al., 2008; Bremer et al., 2011; Watson et al., 2014). However, Veracini et al. (2013) reported an increase in DMI

Table 7. Linear and quadratic interactions for increasing levels of de-oiled or full-fat distillers grains plus solubles on finishing performance (Exp. 3)

		35% WDGS		50% WDGS		65% WDGS			Interaction <i>P</i> value	
	CON ¹	DO ²	FF ³	DO ²	FF ³	DO ²	FF ³	SEM	Linear ⁴	Quadratic ⁵
Performance										
Initial BW, kg	357	358	357	358	356	355	357	36	0.23	0.22
Final BW, kg	614	623	631	631	617	630	623	37	0.26	0.58
DMI, kg/d	11.4	11.5	11.5	11.6	10.9	10.9	10.4	0.8	<0.01	0.48
Intake, % BW ⁶	2.45	2.29	2.22	2.20	2.26	2.22	2.25	0.07	0.52	0.57
ADG, kg	1.76	1.81	1.88	1.88	1.78	1.87	1.84	0.12	0.31	0.64
G:F	0.155	0.158	0.164	0.163	0.164	0.172	0.178	0.007	0.38	0.89
Feeding value ⁷		106%	117%	110%	112%	117%	123%	—	—	—
Energy values ⁸										
NE _m , Mcal/kg	1.81	1.93	2.01	2.02	1.94	2.01	1.99	0.05	0.37	0.48
NE _g , Mcal/kg	1.18	1.28	1.35	1.36	1.23	1.35	1.33	0.05	0.38	0.47

¹Con = corn-based control.²DO = de-oiled WDGS.³FF = full-fat WDGS.⁴Linear = linear interaction *P* value for by-product type and oil concentration.⁵Quadratic = quadratic interaction *P* value for by-product type and oil concentration.⁶Intake, % BW = calculated as the DMI divided by the average BW times 100.⁷Feeding value calculation = difference between the by-product treatment G:F and control G:F divided by control G:F and divided by the treatment inclusion in the diet.⁸Values calculated by pen using the 1996 NRC equations.

when steers were fed 25%, 40%, and 70% reduced fat MDGS in whole shelled corn diets.

For the main effect of oil concentration (Table 8), there were no statistical differences (*P*

Table 8. Main effect of oil concentration on performance and carcass characteristics for 35%, 50%, or 65% distillers grains plus solubles inclusion (Exp. 3)

	De-oiled	Full fat	SEM	<i>P</i> value
Performance				
Initial BW, kg	357	357	0.9	0.48
Final BW ¹ , kg	627	623	9	0.52
DMI, kg/d	11.4	10.9	0.2	<0.01
Intake, % BW ²	2.22	2.22	0.03	0.84
ADG, kg	1.85	1.83	0.07	0.58
G:F	0.163	0.167	0.002	0.19
Energy values³				
NE _m , Mcal/kg	1.99	1.98	0.03	0.88
NE _g , Mcal/kg	1.34	1.33	0.03	0.89
Carcass characteristics				
HCW, kg	394	393	6	0.68
LM area, cm ²	84.6	85.1	0.12	0.58
12th rib fat, cm	1.42	1.42	0.01	0.93
Calculated YG	3.46	3.47	0.06	0.91
Marbling score ⁴	565	576	8	0.34

¹Calculated from hot carcass weight, adjusted to a common dressing percentage of 63.0%.²Intake, % BW = calculated as the DMI divided by the average BW times 100.³Values calculated by pen using the 1996 NRC equations.⁴Marbling score: 500 = Small00.

> 0.19) for initial BW, final BW, ADG, intake as a percentage of BW, G:F, NE_m, or NE_g. Cattle fed DO WDGS had numerically greater final BW and ADG than cattle fed FF WDGS. However, cattle fed FF WDGS had statistically lower DMI (*P* < 0.01), which resulted in a 2.5%, nonsignificant (*P* = 0.19) improvement in G:F compared with cattle fed DO WDGS.

There was no effect on initial BW, final BW, or ADG (*P* ≥ 0.17) as WDGS increased in the diet up to 65% inclusion (DM basis; Table 9). Watson et al. (2014) observed a quadratic response (*P* < 0.01) for final BW and ADG as WDGS increased up to 50% in the diet. The authors reported that feeding 50% WDGS increased ADG and final BW compared with 0% WDGS. Similarly, Bremer et al. (2011) and Corrigan et al. (2009) observed a quadratic response for ADG as the inclusion of WDGS was fed up to 40% inclusion in the diet. In the current study, cattle fed 65% inclusion had statistically similar ADG and final BW compared with CON (*P* ≥ 0.17). A quadratic decrease (*P* < 0.01) in DMI was observed with the greatest reduction in intake observed at the 65% inclusion. Intake as a percentage of BW linearly decreased (*P* < 0.01) as inclusion of WDGS increased in the diet.

With the reduction in DMI as inclusion of WDGS increased and no difference in ADG, a linear increase was observed for G:F as the inclusion of WDGS increased up to 65% in the diet

Table 9. Main effect of inclusion of distillers grains plus solubles on performance and carcass characteristics (Exp. 3)

	Control	35%	50%	65%	SEM	Linear ¹	Quadratic ²
Performance							
Initial BW, kg	357	358	357	356	36	0.22	0.02
Final BW ³ , kg	614	626	624	626	36	0.23	0.46
DMI, kg/d	11.4	11.5	11.2	10.7	0.8	<0.01	<0.01
Intake, % BW ⁴	2.45	2.25	2.23	2.23	0.06	<0.01	0.09
ADG, kg	1.76	1.84	1.83	1.85	0.12	0.17	0.60
G:F	0.155	0.161	0.163	0.175	0.006	<0.01	0.13
Feeding value ⁵	—	111%	110%	120%	—	—	—
Energy values⁶							
NE _m , Mcal/kg	1.82	1.97	1.98	2.00	0.04	<0.01	0.24
NE _g , Mcal/kg	1.18	1.34	1.33	1.34	0.04	<0.01	0.23
Carcass characteristics							
HCW, kg	385	395	393	393	22	0.25	0.27
LM area, cm ²	86.4	85.1	85.9	85.1	0.20	0.53	0.97
12th rib fat, cm	1.32	1.45	1.37	1.42	0.03	0.17	0.37
Calculated YG	3.24	3.49	3.38	3.49	0.12	0.08	0.42
Marbling score ⁷	547	573	555	575	19	0.25	0.79

¹Linear = linear effect of treatment *P* value.²Quadratic = quadratic effect of treatment *P* value.³Calculated from hot carcass weight, adjusted to a common dressing percentage of 63%.⁴Intake, % BW = calculated as the DMI divided by the average BW times 100.⁵Feeding value calculation = difference between the by-product treatment G:F and control G:F divided by control G:F and divided by the treatment inclusion in the diet.⁶Values calculated by pen using the 1996 NRC equations.⁷Marbling score: 500 = Small00.

(DM basis). [Firkins et al. \(1985\)](#) observed a similar linear response for G:F as WDGS increased from 0% to 50% in the diet DM. However, several studies have reported a quadratic response with 40% inclusion of WDGS having the greatest G:F ([Corrigan et al., 2009](#); [Bremer et al., 2011](#); [Watson et al., 2014](#)). A combination of several factors contribute to an increase in feed efficiency when DGS are fed in finishing diets such as the potential for reduced acidosis, improved energy utilization, and additional yeast end products that are added during the fermentation phase of the dry milling process ([Stock et al., 2000](#)). Regardless of oil concentration, as WDGS increased in the diet performance, calculated dietary NE_m and NE_g increased linearly ($P < 0.01$), with the greatest incremental improvement occurring at 35% WDGS. The calculated dietary NE_g was 1.34, 1.33, and 1.34 Mcal/kg for 35%, 50%, and 65% WDGS, respectively, while CON was 1.18 Mcal/kg resulting in 14%, 13%, and 14% more NE_g being provided by the WDGS diets than the CON diet. These improvements in NE_g when cattle are fed WDGS are similar to previous research ([Larson et al., 1993](#); [Ham et al., 1994](#)).

No effect of oil concentration or inclusion of WDGS ($P \geq 0.08$; [Table 9](#)) was observed for HCW, LM area, 12th rib fat thickness, calculated yield grade, or marbling score.

Based on this research, reducing the oil concentration, via centrifugation from CDS, does not affect ADG or G:F in finishing steers fed diets with either distillers grains plus solubles or solubles alone when substituted for dry-rolled and high-moisture corn. However, replacing corn with DGS or CDS in finishing diets increased ADG and G:F, regardless of fat concentration. Feeding DO CDS does appear to reduce total tract fat digestibility and DE (megacalorie per kilogram) compared with FF CDS; however, this did not appear to impact gain or efficiency.

LITERATURE CITED

- AOAC. 1999. Official methods of analysis. 16th ed. Assoc. Off. Anal. Chem., Arlington, VA.
- Boggs, D. L., and R. A. Merkel. 1993. Beef carcass evaluation, grading, and pricing. Kendel/Hunt Publ. Co, Dubuque, IA.
- Brandt, R. T., Jr., and S. J. Anderson. 1990. Supplemental fat source affects feedlot performance and carcass traits of finishing yearling steers and estimated diet net energy value. *J. Anim. Sci.* 68:2208–2216.

- Bremer, V. R., C. D. Buckner, A. W. Brown, T. P. Carr, R. M. Diedrichsen, G. E. Erickson, and T. J. Klopfenstein. 2010a. Lipid and NDF analysis of ethanol byproduct feedstuffs. *Nebr. Beef Cattle Rep.* MP-93:83–86.
- Bremer, V. R., K. M. Rolfe, C. D. Buckner, G. E. Erickson, and T. J. Klopfenstein. 2010b. Metabolism characteristics of feedlot diets containing different fat sources. *Nebr. Beef Cattle Rep.* MP-93:80–82.
- Bremer, V. R., A. K. Watson, A. J. Liska, G. E. Erickson, K. G. Cassman, K. J. Hanford, and T. J. Klopfenstein. 2011. Effect of distillers grains moisture and inclusion level in livestock diets on greenhouse gas emissions in the corn-ethanol-livestock life cycle. *Prof. Anim. Sci.* 27:449–455.
- Buckner, C. D., M. F. Wilken, J. R. Benton, S. J. Vanness, V. R. Bremer, T. J. Klopfenstein, P. J. Kononoff, and G. E. Erickson. 2011. Nutrient variability for distillers grains plus solubles and dry matter determination of ethanol by-products. *Prof. Anim. Sci.* 27:57–64.
- Cochran, R. C., and M. L. Galyean. 1994. Measurement of in vivo forage digestion by ruminants. In: G. C. Fahey, editor. *Forage quality, evaluation, and utilization*. ASA, CSSA, SSSA, Madison, WI. p. 613–643. doi:10.2134/1994.foragequality.c15
- Cooper, R. J., T. J. Klopfenstein, R. A. Stock, C. T. Milton, D. W. Herold, and J. C. Parrott. 1999. Effects of imposed feed intake variation on acidosis and performance of finishing steers. *J. Anim. Sci.* 77:1093–1099.
- Corrigan, M. E., G. E. Erickson, T. J. Klopfenstein, M. K. Luebke, K. J. Vander Pol, N. F. Meyer, C. D. Buckner, S. J. Vanness, and K. J. Hanford. 2009. Effect of corn processing method and corn wet distillers grains plus solubles inclusion level in finishing steers. *J. Anim. Sci.* 87:3351–3362. doi:10.2527/jas.2009-1836
- Firkins, J. L., L. L. Berger, and G. C. Fahey. 1985. Evaluation of wet and dry distillers grains and wet and dry corn gluten feed for ruminants. *J. Anim. Sci.* 60:847–860.
- Galyean, M. 2017. The home page of Michael Galyean. NEM and NEM Calculations. <http://www.depts.ttu.edu/afs/home/mgalyean/> (Accessed 30 August 2017).
- Ham, G. A., R. A. Stock, T. J. Klopfenstein, E. M. Larson, D. H. Shain, and R. P. Huffman. 1994. Wet corn distillers byproducts compared with dried corn distillers grains with solubles as a source of protein and energy for ruminants. *J. Anim. Sci.* 72:3246–3257.
- Hales, K. E., N. A. Cole, and J. C. MacDonald. 2012. Effects of corn processing method and dietary inclusion of wet distillers grains with solubles on energy metabolism, carbon-nitrogen balance, and methane emissions of cattle. *J. Anim. Sci.* 90:3174–3185. doi:10.2527/jas.2011-4441
- Hales, K. E., J. P. Jaderborg, and G. I. Crawford. 2015. Effects of dry-rolled or high-moisture corn with twenty-five or forty-five percent wet distillers' grains with solubles on energy metabolism, nutrient digestibility, and macromineral balance in finishing beef steers. *J. Anim. Sci.* 93:4995–5005.
- Hall, M. B., and M. L. Eastridge. 2014. Carbohydrate and fat: considerations for energy and more. *Prof. Anim. Sci.* 30:140–149.
- Hatch, C. F., T. W. Perry, M. T. Mohler, and W. M. Beeson. 1972. Effect of added fat with graded levels of calcium to urea-containing rations for beef cattle. *J. Anim. Sci.* 43:483–491.
- Huffman, R. P., R. A. Stock, M. H. Sindt, and D. H. Shain. 1992. Effect of fat type and forage level on performance of finishing cattle. *J. Anim. Sci.* 70:3889–3898.
- Klopfenstein, T. J., G. E. Erickson, and V. R. Bremer. 2008. Board-invited review: use of distillers by-products in the beef cattle feeding industry. *J. Anim. Sci.* 86:1223–1231. doi:10.2527/jas.2007-0550
- Larson, E. M., R. A. Stock, T. J. Klopfenstein, M. H. Sindt, and R. P. Huffman. 1993. Feeding value of wet distillers byproducts for finishing ruminants. *J. Anim. Sci.* 71:2228–2236.
- Musser, R. 2013. Corn, ethanol plants, oil extraction, and the changes in nutrient composition of distillers grains. http://lib.dr.iastate.edu/dgtc_symposium/2013/Presentations/4 (Accessed 12 September 2016).
- Myers, W. D., P. A. Ludden, V. Nayigihugu, and B. W. Hess. 2004. Technical note: A procedure for the preparation and quantitative analysis of samples for titanium dioxide. *J. Anim. Sci.* 82:179–183.
- National Research Council. 1996. *Nutrient requirements of beef cattle*. 7th ed. Natl Acad. Press, Washington, DC.
- Pesta, A. C., B. L. Nuttelman, A. L. Shreck, W. A. Griffin, T. J. Klopfenstein, and G. E. Erickson. 2015. Finishing performance of feedlot cattle fed condensed distillers solubles. *J. Anim. Sci.* 93:4350–4357. doi:10.2527/jas.2015-9247
- Pesta, A. C., A. L. Shreck, T. J. Klopfenstein, and G. E. Erickson. 2012. Metabolism of finishing diets containing condensed distillers solubles and WDGS. *Nebr. Beef Cattle Rep.* MP-97:68–69.
- Renewable Fuels Association. 2016. Pocket guide to ethanol 2016. www.ethanolrfa.org (Accessed 12 September 2016).
- Stock, R., T. Klopfenstein, D. Brink, S. Lowry, D. Rock, and S. Abrams. 1983. Impact of weighing procedures and variation in protein degradation rate on measured performance of growing lambs and cattle. *J. Anim. Sci.* 57:1276–1285.
- Stock, R. A., J. M. Lewis, T. J. Klopfenstein, and C. T. Milton. 2000. Review of new information on the use of wet and dry milling feed by-products in feedlot diets. *J. Anim. Sci.* 77:1–12.
- Titlow, A. H., A. L. Shreck, S. A. Furman, K. H. Jenkins, M. K. Luebke, and G. E. Erickson. 2013. Replacing steam-flaked corn and dry rolled corn with condensed distillers solubles in finishing diets. *Nebr. Beef Cattle Rep.* MP-98:51–52.
- Trenkle, A. 2003. Relative feeding value of wet corn distillers solubles as a feed for finishing cattle. Beef Research Report ASL R1772, Iowa State University, Ames, IA. http://lib.dr.iastate.edu/beefreports_2002/1 (Accessed 29 March 2018).
- Trenkle, A. and D. Pingel. 2004. Effects of replacing corn grain and urea with condensed distillers solubles on performance and carcass value of finishing steers. Animal Industry Report: AS 650, ASL R1884. Iowa State University, Ames, IA. https://lib.dr.iastate.edu/ans_air/vol650/iss1/43 (Accessed 29 March 2018).
- U.S. Grains Council. 2012. A guide to distiller's dried grains with solubles (DDGS). 3rd ed. www.ethanolrfa.org (Accessed 25 October 2013).
- Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74:3583–3597. doi:10.3168/jds.S0022-0302(91)78551-2
- Vander Pol, K. J., M. K. Luebke, G. I. Crawford, G. E. Erickson, and T. J. Klopfenstein. 2009. Performance and digestibility characteristics of finishing diets containing distillers grains, composites of corn processing coproducts,

- or supplemental corn oil. *J. Anim. Sci.* 87:639–652. doi:10.2527/jas.2008-1036
- Veracini, J. L., P. M. Walker, B. R. Wiegand, R. L. Atkinson, M. J. Faulkner, and L. A. Forster. 2013. Effects of reduced-fat modified wet distillers grains with solubles on beef steer performance and carcass composition. *Prof. Anim. Sci.* 29:518–528.
- Watson, A. K., B. L. Nuttelman, T. J. Klopfenstein, L. W. Lomas, and G. E. Erickson. 2013. Impacts of a limit-feeding procedure on variation and accuracy of cattle weights. *J. Anim. Sci.* 91:5507–5517. doi:10.2527/jas.2013-6349
- Watson, A. K., K. J. Vander Pol, T. J. Huls, M. K. Luebke, G. E. Erickson, T. J. Klopfenstein, and M. A. Greenquist. 2014. Effect of dietary inclusion of wet or modified distillers grains plus solubles on performance of finishing cattle. *Prof. Anim. Sci.* 30:585–596.
- Zinn, R. A. 1989a. Influence of level and source of dietary fat on its comparative feeding value in finishing diets for steers: Feedlot cattle growth and performance. *J. Anim. Sci.* 67:1029–1037.
- Zinn, R. A. 1989b. Influence of level and source of dietary fat on its comparative feeding value in finishing diets for feedlot steers: Metabolism. *J. Anim. Sci.* 67:1038–1049.
- Zinn, R. A. 1994. Effects of excessive supplemental fat on feedlot cattle growth performance and digestive function. *Prof. Anim. Sci.* 10:66–72.
- Zinn, R. A., S. K. Gulati, A. Plascencia, and J. Salinas. 2000. Influence of ruminal biohydrogenation on the feeding value of fat in finishing diets for feedlot cattle. *J. Anim. Sci.* 78:1738–1746.
- Zinn, R. A., and Y. Shen. 1996. Interaction of dietary calcium and supplemental fat on digestive function and growth performance in feedlot steers. *J. Anim. Sci.* 74:2303–2309.